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ENERGY IN DEVELOPING COUNTRIES

CONGRESS OF THE UNITED STATES
OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

This report was prepared in the course of the ongoing OTA Assessment, *Fueling Development: Energy and Technology in Developing Countries*, which is being carried out in response to requests from the Senate Committee on Governmental Affairs; the House Committee on Energy and Commerce; the Subcommittee on Energy and Power of the House Committee on Energy and Commerce; the Subcommittee on Human Rights and International Organizations and the Subcommittee on Africa of the House Committee on Foreign Affairs; the Subcommittee on International Development, Finance, Trade and Monetary Policy of the House Banking Committee; and individual members of the Senate Environment and Public Works Committee; the House Select Committee on Hunger; and the Congressional Competitiveness Caucus.

These committees and subcommittees asked OTA to examine the role of technology in providing cost effective energy services that poor countries need for their economic and social development, while minimizing adverse environmental impacts. The committees were particularly interested in an analysis of the U.S. role in facilitating the adoption of such technologies. The overall assessment is scheduled for completion in 1991. This report, the first of two, was prepared in response to the requesting committees' interest in receiving an interim product. It examines how energy is supplied and used in developing countries, and how energy use is linked with economic and social development and environmental quality.

OTA received substantial help from many organizations and individuals in the course of preparing this report. We are very grateful for the efforts of the project's contractors, who prepared parts of the background analysis; members of the advisory panel; and workshop participants, who provided guidance and extensive critical reviews; and the many additional reviewers who gave their time to ensure the accuracy of this analysis.

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Chapter 1

Introduction and Overview

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Chapter 1
Introduction and Overview

Introduction

Energy use in developing countries has risen more than fourfold over the past three decades and is expected to continue increasing rapidly in the future. The increase in the services that energy provides is necessary and desirable, since energy services are essential for economic growth, improved living standards, and to provide for increased human populations. But finding the energy supplies to provide these services could cause major economic and social problems. For many of the developing countries, much of the additional energy needed will be supplied by imported oil, and rising oil imports will further burden those countries already saddled with high oil import bills. Similarly, building dams or powerplants to meet higher demands for electricity could push these nations even deeper into debt. Energy development and use also contribute to local environmental damage in developing countries, including record levels of air pollution in some urban areas.

The rapid growth of energy use in developing countries has wide impacts. The economic development process has traditionally been accompanied by rapid increases in oil demand, which, together with rising demand in the industrial countries, contribute to upward pressures on world oil prices. High levels of indebtedness in the developing countries, partly energy-related, have already contributed to instability in the international money and banking system. Rapid increases in fossil fuel use in developing countries also represent a growing contribution to the increase in local and regional air pollution as well as atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2). International efforts to control greenhouse gas emissions require active participation by developing countries. Many developing countries could be adversely affected by climate change, some much more than most industrial nations.

An economically and environmentally sound approach to energy development offers potentially large benefits both for the developing countries and for the rest of the world. It can contribute to economic growth in the developing countries, leading to higher living standards, reduction of hunger and poverty, and better environmental quality. This strategy also holds benefits for the richer countries. The developing countries are important trading partners for the United States. More rapid economic growth in these countries could stimulate U.S. exports, including exports of energy technology products, and, therefore, could benefit the U.S. trade balance. Improved energy technologies can slow the rate of increase in greenhouse gas emissions—a global benefit.

The Purpose of This Assessment

This report is part of an assessment entitled "Fueling Development: Energy and Technology in the Developing Countries," requested by the Senate Committee on Governmental Affairs; the House Committee on Energy and Commerce; the Subcommittee on Energy and Power of the House Committee on Energy and Commerce; the Subcommittee on Human Rights and International Organizations and the Subcommittee on Africa of the House Committee on Foreign Affairs; the Subcommittee on International Development, Finance, Trade and Monetary Policy of the House Banking Committee; and individual members of the Senate Environment and Public Works Committee, the House Select Committee on Hunger, and the Congressional Competitiveness Caucus.

The Office of Technology Assessment (OTA) was asked to examine the extent to which technology can provide the energy services that developing countries need for economic and social development in a cost-effective and socially viable manner, while minimizing the adverse environmental impacts; and to evaluate the role of the United States in accelerating the adoption of such technologies by developing countries.

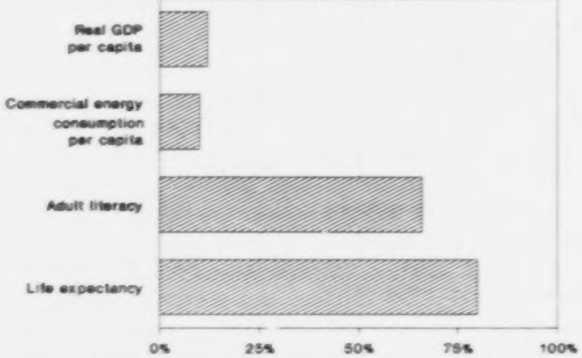
This report, the first product of the assessment, examines how energy is currently supplied and used in the developing countries and how energy is linked with economic and social development and the quality of the environment. Our emphasis is primarily on the present status of developing countries, and concerns about current energy trends. This report is intended to provide an introduction to the problems, challenges, and opportunities associated with providing energy services for economic and social development in the developing countries. These issues are examined under four broad topic areas: energy and economic development (ch. 2); energy services (ch. 3); energy supplies (ch. 4); and energy use and the environment (ch. 5). A subsequent report will present the results of OTA's assessment of technologies that can potentially improve the efficiency of both energy production and use in developing countries; an examination of the technology transfer process; and ways in which Congress can help promote the rapid adoption of such policies.

The Developing World and the Industrialized World

We largely follow the definition of "developing" countries—low- and middle-income countries (further divided into lower middle and upper middle countries)—used by the World Bank[1] (see app. 1A for a list of these countries), including all of the countries of Africa, Latin America, and Asia, excluding Japan.[2]

There are wide differences in *average* indicators of social and economic conditions between developing and industrial countries (figure 1-1).

Figure 1-1—Differences Between Developing and Industrial Nations (developing nation average as a share of industrial* nation average)



How to interpret this figure. The average values for the industrial countries are assigned 100 in all cases. The values for the developing countries are expressed as a share of 100. For example, average life expectancy in the industrial nations is 76 years and in the developing nations 62 years, or 82 percent of the industrial country level.

*Industrial excludes the U.S.S.R.; based on weighted average of high-income market economies.

SOURCE: United Nations, *Human Development Report 1990*; World Bank, *World Development Report*.

1. *Social*: The citizens of (OECD) countries have a longer life expectancy (76 years, compared with an average of 62 in developing countries), largely due to lower infant mortality rates (9 per 1,000 live births compared with 71 in developing countries). A much larger share of the population has access to secondary and higher education and health care.

2. *Economic*: Average per-capita incomes[3] (expressed in purchasing power parities[4]) are more than eight times higher in OECD countries than in the developing countries. This difference in income levels reflects major differences in economic structure, particularly the higher share of agriculture in total production in the developing countries. A much lower share of

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[1] See, for example, World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), pp. 164-165.

[2] The definition of developing countries is based primarily on per-capita income levels. This ranking system is rather arbitrary, however; if all the countries of the world are ranked by ascending level of per-capita income, there is no obvious gap in the series to demarcate the two groups of countries. The World Bank distinguishes six categories of countries: low-income, lower-middle-income, upper-middle-income, high-income oil-exporters, industrial market economies, including OECD as a subset, and "non-reporting non-members" (the U.S.S.R., North Korea, East Germany, Angola, Bulgaria, Albania, Mongolia, and Namibia). The group of developing countries (low- and middle-income and upper-middle-income countries) does not include Saudi Arabia, Kuwait, and the United Arab Emirates by virtue of their high per-capita income. The World Bank does, however, include as developing countries some East and West European countries, such as Poland, Hungary, Yugoslavia, Greece, and Turkey, that qualify as developing countries by virtue of their income levels, but, due to their integration with industrial economies of East and West Europe, do not share other characteristics of underdevelopment, and are therefore not included in this report. Some other countries are excluded due to lack of reported data. Where group averages of general economic and social indicators are reported directly from the *World Development Report*, these countries are included in the total. In more detailed analysis, they are excluded. While every effort is made to adhere to these definitions, it is not always possible, especially when other sources of data with slightly different definitions are used.

[3] Income is usually measured by Gross Domestic or Gross National Product. The difference between the two—typically small for most countries—is that GDP measures the total output of goods and services within the national border of a country, whereas GNP measures the output of goods and services attributable to the nationals of a country wherever that activity occurs.

[4] If market exchange rates are used to convert the GDP of different countries to dollars, average OECD per-capita income appears to be over 20 times higher than average developing country per-capita income. If, however, the comparison of income levels is adjusted to take into account differences in purchasing power of currencies (i.e., what a unit of currency such as the dollar will buy in different countries) the gap between average per-capita income levels in developing and OECD countries narrows, and OECD per-capita income levels are 8 times rather than 20 times higher than the developing country average. In either case, the gap in income levels is substantial.

the population lives in urban areas—37 percent in the developing countries compared with 77 percent in the OECD countries. Population growth is more rapid in developing countries. It is estimated to double by 2040, while the population of the industrial world will increase by only 15 percent over the same period.

3. *Energy*: The economic and social contrasts are also reflected in energy consumption. Per-capita consumption of commercial energy (coal, oil, gas, and electricity)[5] in the OECD countries is on average 10 times higher than in the developing countries. On the other hand, commercial energy consumption is increasing much faster in the developing countries. Biomass energy consumption in the developing countries is higher than in the OECD countries and provides a much higher share of total energy consumption.

Similarities and Differences Among Developing Countries

The developing country averages shown in figure 1-1, though adequate to illustrate the broad contrasts between developing and industrial countries, obscure the wide economic and social differences among developing countries. Indeed, the range of differences between LDCs is greater than that between many of them and the industrial countries. A generation of exceptionally fast economic growth in the Newly Industrialized Countries (the NICs), combined with the slow growth, or in some cases, economic stagnation and decline, in many African countries, has widened the gap among developing countries. Thus the problems, energy or otherwise, faced by a relatively rich and developed country such as Brazil are different from those faced by a poor country like Ethiopia, as are the resources available for their solution. An appreciation of these differences is necessary for the realistic assessment of energy technologies.

Per-capita incomes in the upper middle-income developing countries (e.g., Brazil, Argentina, Algeria, Venezuela, and Korea) are almost seven times higher than in the low-income countries (table 1-1).[6] The income differential reflects major differences in economic structure. In the upper middle-income countries, industry has a much larger share in total output and agriculture a much lower share. India and China are exceptions, with atypically large shares of industry, given their levels of income. The share of the total population living in urban areas is much lower in the low-income countries. For example, in several African countries only about 10 percent of the total population is urban[7] dwellers, in contrast to countries like Brazil, Argentina, and Venezuela, whose levels of urbanization (about 80 percent of the population living in towns) are similar to those in the industrial countries.

Developing countries also show wide variations in social indicators. Life expectancy at birth rises from an average of 54 years in the low-income developing countries to an average of 67 in the upper middle-income countries. Infant mortality is twice as high in the low-income countries (over 100 per 1,000 births compared with an average of 50 in the upper middle-income developing countries). India and China are again exceptions: in both countries, despite lower average income, indicators of social development are similar to those found in countries with much higher incomes. The experience of these two countries testifies to the importance of social policies in achieving relatively high levels of social development despite low incomes.[8] Population growth rates also differ widely among developing countries. In recent years these have ranged from about 1 percent annually in some countries (e.g., China, Uruguay, Korea) to over 3 percent in several African countries.

The wide variations in social and economic conditions in developing countries are also reflected in their energy use. In the upper middle income de-

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[5] The term "commercial energy" conventionally applies to coal, oil, gas, and electricity on the basis that they are widely traded in organized markets. These fuels are distinguished from other fuels such as firewood, charcoal, and animal and crop wastes, which are described as "biomass" or "noncommercial fuels." The distinction between them can be misleading, particularly in the context of developing countries, as some of the so-called "noncommercial" fuels, such as firewood and charcoal, are also widely traded in highly organized markets. To minimize this ambiguity we use the term "biomass energy" here.

[6] See also app. 1A.

[7] Estimates of urban populations are based on country-specific criteria related to size of settlement and presence of urban characteristics.

[8] This theme is developed further in a recent publication by the United Nations Development Programme, *Human Development Report 1990* (New York, NY: Oxford University Press, 1990).

[9] See footnote 5.

Table 1-1—Heterogeneity of the Developing World: Social, Economic, and Energy Indicators

Indicators	Year	Low-income countries	India and China	Lower middle-income countries	Upper middle-income countries
Economic:					
GNP per capita ($1987) (ppp)[a]	1987	840.0	900.0	3,000.0	5,420.0
Share agriculture in GDP (%)[b]	1987*	33.0	30.0	21.0	10.0*
Urban population as share of total (%)[c]	1987	24.0	33.0	51.0	66.0
Cars and trucks per 1,000 members of population[d]	1980*	3.2	3.2	19.3	93.3
Social:					
Life expectancy at birth (years)[e]	1987	54.0	65.0	64.0	67.0
Infant mortality per 100 births[f]	1987	103.0	62.0	61.0	50.0
Share of age group with secondary education (%)[g]	1986	25.0	39.0	51.0	59.0
Energy:					
Commercial energy consumption per capita (gigajoules)[h]	1986	4.9	16.3	36.2	58.3
Total energy consumption per capita (gigajoules)[i]	1986	12.3	18.7	41.7	67.0**
Share of traditional energy in total (%)[j]	1986	60.0	13.0	13.0	13.0**

* Estimated.

** If Brazil is excluded, the total per capita energy consumption would be 62 gigajoules and the share of traditional energy in total 2 percent.

SOURCES: [a] World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989). Purchasing power parity (ppp) estimate based on data on pp. 164 and 222.

[b] Ibid., based on data in table 3.

[c] Ibid., table 31.

[d] Joy Dunkerley and Irving Hoch, *Transport Energy: Determinants and Policy* (Washington, DC: Resources for the Future, September 1985), table 5-1 and appendix table 13. Based on estimates. Note that totals are unweighted averages and the countries included differ slightly from *World Development Report 1989*.

[e] World Bank, op. cit., table 1.

[f] Ibid., table 32.

[g] Ibid., table 29.

[h] Ibid, table 8.

[i] United Nations, *Energy Statistics Yearbook 1986* (New York, NY: United Nations, 1988), table 4.

[j] These values for the share of traditional energy are much lower than those found in field surveys. These values are presented here in order to have a consistent data set. Estimates based on field surveys suggest that biomass provides one-third of the energy used by developing countries overall (chs. 3 and 4).

Table 1-2—Commercial Energy Import Dependence in Developing Countries

Country income group	Number of countries in group[a]	Number of energy exporters	Number of energy importers	High importers (70-100%)[b]	Medium importers (30-70%)[b]	Low importers (0-30%)[b]
Low-income	38	4	34	29	3	2
China and India	2	1	1	0	0	1
Lower middle-income	30	10	20	15	3	2
Upper middle-income	10	6	4	2	1	1
Total	80	21	59	46	7	6

[a] Includes all countries for which import dependence data are available.
[b] Shares of imports in total commercial energy consumption.

SOURCE: Based on data in the United Nations, *1986 Energy Statistics Yearbook* (New York, NY: 1988).

veloping countries, per-capita annual *commercial*[9] energy consumption (at 60 gigajoules[10]) is 12 times higher than in the low-income countries (5 GJ).[11] Again China and India differ from the other low-income countries, with per-capita consumption of commercial energy more than 3 times higher than other low-income countries. Per-capita consumption of *traditional* biomass fuels, on the other hand, is generally higher in the poorest countries, depending on the biomass resources available.[12]

There are similarly large variations in energy resource endowment. While many countries have some energy resources, three-quarters of the developing countries depend on imports for part or all of their commercial energy supplies (table 1-2). Levels of import dependence vary, but in many countries, imports (almost entirely oil) provide nearly all commercial energy supplies. Oil imports can be a considerable strain on already tight foreign exchange budgets. In several countries, particularly in Africa and Central America, oil imports represent over 30 percent of foreign exchange earnings from exports (see app. 1A).

Despite these differences in aggregate indicators, there are strong similarities among developing countries within specific sectors. Energy use in traditional villages throughout the developing world is fairly similar in terms of quantity used, source (biomass, muscle power), and services provided (cooking, subsistence agriculture). At the other end of the scale, energy use by the economically well off is also reasonably similar between developing and industrial countries, in terms of quantity used (to within a factor of 2 or 3), source (oil, gas, coal, electricity), and services provided (electric lighting and appliances, industrial goods, private automobiles, etc.). The large differences between countries are then in large part due to the relative share of the total traditional villagers and the economically well off in the population, and in the forms and quantities of energy used by those who are making the transition between these two extremes. The broad similarities *within* specific population sectors imply that it is possible to make generalizations about technology that are applicable to a wide range of otherwise disparate countries.

The Developing World in Global Energy[13]

The developing countries now account for about 30 percent of global energy use, including both commercial and traditional energy (see table 1-3), and their share is growing rapidly. Their use of the different fuels vary widely: they account for 85 percent of biomass fuel consumption but only 23 percent of commercial fuels (oil, gas, coal, and electricity). The main sources of energy for the developing countries as a group are coal, oil, and

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[9] See footnote 5.

[10] A gigajoule (GJ), or 1 billion joules, is about the energy content of 8 gallons of gasoline. For reference, annual per-capita energy consumption in the United States is 327 million British thermal units (Btu) or 343 gigajoules. An exajoule (EJ), or 10^{18} joules, is about the same as a Quad (1.05 EJ = 1 Quad).

[11] World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989). Data, from p. 172, in tonnes of oil equivalent (toe) converted to gigajoules at 1 toe = 41.9 gigajoules.

[12] Brazil, despite its relatively high income, uses substantial quantities of biomass fuels in modern applications, such as charcoal for steelmaking and ethanol for cars. This contrasts with the use of biomass in the poorer countries, as a cooking fuel using traditional technologies.

[13] The data in this section are taken from the World Energy Conference, *Global Energy Perspectives 2000-2020*, 14th Congress, Montreal 1989 (Paris 1989); and the United Nations, *1986 Energy Statistics Yearbook* (New York, NY: 1988), updated to 1987 by data provided by the U.N. Secretariat.

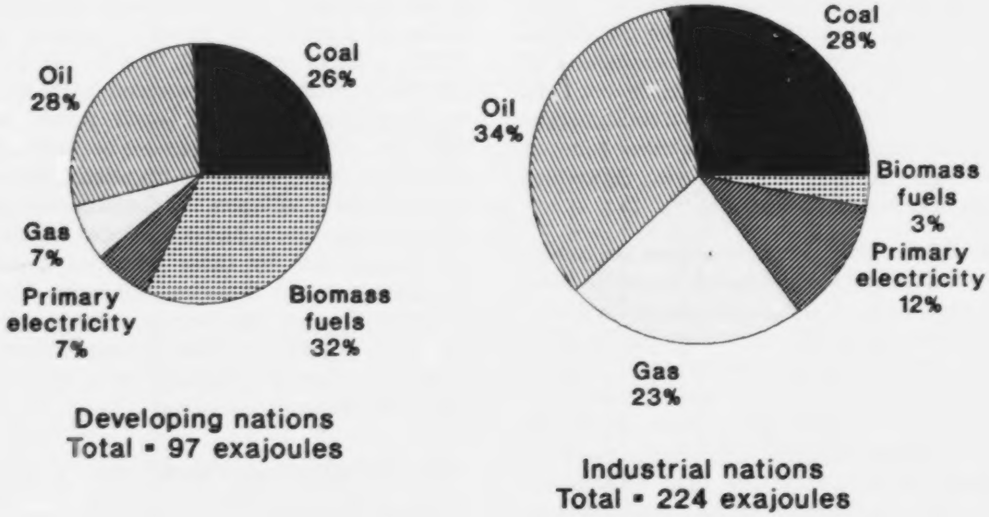
Table 1-3—1985 Primary Energy Supplies (exajoules)

	Coal	Oil	Gas	Primary electricity	Total commercial	Biomass	Total energy
World	88.7	104.6	58.2	33.0	284.5	36.9	321.3
Industrial countries	63.5	77.0	51.7	26.6	218.7	5.5	224.2
Developing countries	25.2	27.7	6.5	6.4	65.7	31.3	97.1
Share of industrial countries	72%	74%	89%	81%	77%	15%	70%
Share of developing countries	28%	26%	11%	19%	23%	85%	30%

NOTE: As in table 1-1, the values reported for developing country biomass are too low. Field surveys indicate that biomass accounts for roughly one-third of the energy used in developing countries.

SOURCE: World Energy Conference, *Global Energy Perspectives 2000-2020*, 14th Congress, Montreal 1989 (Paris: 1989).

Figure 1-2—1985 Energy Consumption, Industrial and Developing Region Fuel Mix



Developing nations
Total = 97 exajoules

Industrial nations
Total = 224 exajoules

SOURCE: World Energy Conference, *Global Energy Perspectives 2000-2020*, 14th Congress, Montreal 1989 (Paris: 1989).

biomass (see figure 1-2). However, much of the coal is used in India and China only. The other developing countries rely heavily on oil and biomass for their energy supplies. Several developing countries—China, India, Mexico, Brazil, and South Africa—are among the world's 20 largest commercial energy consumers (see table 1-4). China alone accounts for almost 10 percent of the world's total commercial energy use.

Three countries—China, India, and Brazil—together account for about 45 percent of total developing country consumption of both commercial and biomass fuels. And these countries plus four more—Indonesia, Mexico, Korea, and Venezuela—account for 57 percent of the total. At the other end of the scale are a large number of small countries that, combined, account for only a small part of global consumption. The 50 countries of Africa, for example, use under 3 percent of total world commercial energy consumption. Concerns about global energy use and its implications focus attention on the large consumers, but the energy needs of the small developing nations, though of lesser importance to global totals, are critical to their development prospects.

The developing countries are becoming increasingly important actors in global commercial energy. Their share of the total has risen sharply in recent years (see figure 1-3), from 17 percent of global commercial energy in 1973 to over 23 percent now. Despite their much lower levels of per-capita commercial energy consumption, developing coun-

Table 1-4—Largest Energy Consumers, 1987

Country	Total commercial energy consumption (exajoules)	Per-capita commercial energy consumption (gigajoules)
20 largest commercial energy consumers:		
Rank		
1 United States	68.1	280
2 U.S.S.R.	54.7	194
3 China	23.5	22
4 Japan	13.4	110
5 West Germany	10.0	165
6 United Kingdom	8.5	150
7 Canada	7.5	291
8 India	6.5	8
9 France	6.1	109
10 Italy	6.0	105
11 Poland	5.3	141
12 Mexico	4.1	50
13 East Germany	3.8	231
14 Australia	3.2	201
15 Brazil	3.2	22
16 South Africa	3.2	83
17 Romania	3.1	136
18 Netherlands	3.1	213
19 Czechoslovakia	2.9	185
20 Spain	2.4	147
10 largest developing country energy consumers:		
Rank		
1 China	23.5	22
2 India	6.5	8
3 Mexico	4.1	50
4 Brazil	3.2	22
5 South Africa	3.2	83
6 South Korea	2.2	52
7 Argentina	1.7	56
8 Venezuela	1.6	88
9 Indonesia	1.4	8
10 Egypt	1.0	20

NOTE: Data for the top 10 developing country energy consumers include only countries listed in app. 1A.

SOURCE: United Nations Secretariat.

tries accounted for one-half of the total *increase* in global commercial energy consumption since 1973.

The increasing share of the developing countries in global commercial energy consumption is widely predicted to continue. The World Energy Conference projects an increase in their share to 40 percent by 2020 (see figure 1-3), and this trend is confirmed in a large number of other studies.[14] The developing countries are projected to account for almost 60 percent of the global *increase* (over current levels) in commercial energy consumption by 2020. China alone accounts for over one-third of this increase. These increasing shares are sufficiently large to have a major impact on world energy markets. Despite the more rapid rate of growth in energy consumption in developing countries, their per-capita consumption of commercial energy will still continue to be far below the levels in industrial countries (see figure 1-4).

Analytic Focus

The analysis presented in this OTA study has three important features. First, rather than concentrating on energy supplies, the analysis focuses on the services energy provides. The reason for this approach is simple. Energy is not used for its own sake, but rather for the services it makes possible—cooking, heating water, cooling a house, heating an industrial boiler, transporting freight and people. Further, there may be many different means of providing a desired service, each with its own costs and benefits. For example, transport is provided in a number of ways—bicycle, motorcycle, car, bus, light rail, or aircraft. The consumer chooses among these according to such criteria as cost, comfort, convenience, speed, and even aesthetics. Within these consumer constraints, a more efficient car may be preferable to increasing refinery capacity in order to reduce capital and/or operating costs, or because of environmental benefits. More than just engineering and economics must be considered, including social, cultural, and institutional factors. Such factors are more readily included in a services framework than in a conventional energy supply analysis.

Second, within this services framework the changes in how energy is used are traced from traditional rural areas to their modern urban counterparts. This

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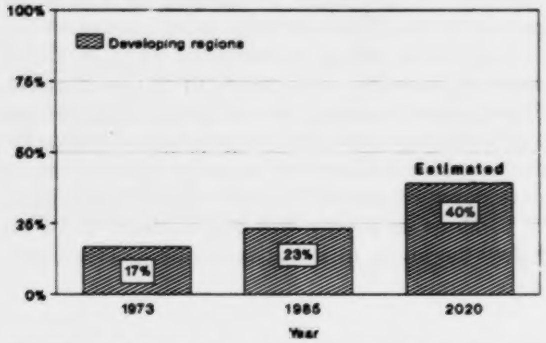
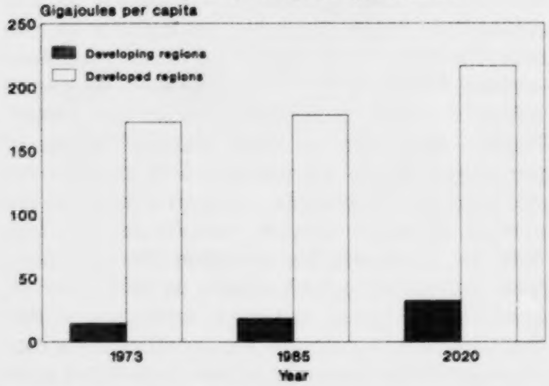
[14] An analysis of projections of global commercial energy consumption over the next 20 years in Allan S. Manne and Leo Schrattenholzer, *International Energy Workshop: Overview of Poll Responses* (Stanford University International Energy Project, July 1989), reports the results and assumptions of over 100 projections of global energy consumption and production, and provides the means of the different studies. Not all studies report results for all regions. The coverage is nonetheless a comprehensive indicator of how energy forecasters view the future. They suggest that the developing countries' share could rise to over one-third by 2010. Longer term projections in general arrive at similar conclusions. For example, the *Emissions Scenarios* document, prepared by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change, Appendix Report of the Expert Group on Emissions Scenarios (RSWG Steering Committee, Task A), April 1990, concludes that, over a wide range of scenarios, the share of developing countries (Centrally Planned Asia, Africa, Middle East, and South and East Asia) will increase from a 1985 reference level of 23 percent to between 40 and 60 percent of global energy in 2100, and that this group of developing countries would account for between 60 and 80 percent of the total increase in energy consumption over this period. Further, developments in the developing countries define much of the difference between the low and high growth scenarios.

Figure 1-3—Commercial Energy Consumption, 1973, 1985, and 2020 (developing nation energy demand as a percentage of world total)



SOURCE: World Energy Conference, *Global Energy Perspectives 2000-2020*, 14th Congress, Montreal 1989 (Paris: 1989).

Figure 1-4—Per-Capita Commercial Energy Consumption, 1973, 1985, and 2020



SOURCE: World Energy Conference, *Global Energy Perspectives 2000-2020*, 14th Congress, Montreal 1989 (Paris: 1989).

progression from the traditional rural to the modern urban helps illuminate the dynamics of energy use, and how it can be expected to change in the future.

Third, the entire system needed to provide energy services—from the energy resource to the final energy service, including production, conversion, and use—is examined as a whole. This is done in order to show the total costs and consequences to society, as well as to the individual, of providing particular services, and how they might be provided more effectively in terms of financial, environmental, and other costs. For example, increased lighting services can be met by using more conventional lighting and increasing the amount of electricity generated, by increasing the use of more efficient light bulbs, or by a combination of the two. A systems approach permits the comparison of efficiency and supply options in achieving the desired end.

In our analysis of energy services and systems it is recognized that technology adoption and use is embedded in an institutional framework that provides both incentives and disincentives to users, and largely determines which and how technologies will be used. This approach has a number of implications both for the way technology is used now and for the adoption of new technologies in the future. Thus, the energy sector in many developing countries is frequently characterized as "inefficient" in the sense that more energy is used to provide a given service or output than is usual in industrial countries. In a wider context, however, taking into account the many other relevant factors (financial, infrastructural, managerial, and institutional), the technology may well be used to the best of human ability and often with considerable ingenuity and resourcefulness. In many cases, although energy *appears* to be used inefficiently, energy users may be acting logically given the framework of incentives and disincentives within which they make their decisions. It follows therefore that the adoption of a new technology will depend not only on the intrinsic superiority of the technology itself but also on whether institutional factors favor its adoption. The policy environment is of crucial importance to the adoption of new technologies.

Overview of the Report

Energy consumption in the developing world has risen rapidly in the past and is widely expected to continue increasing rapidly in the future. The World Energy Conference, for example, projects (in its "moderate" economic growth case) a tripling in consumption of commercial energy in developing countries between now and 2020. A survey of a large number of projections of commercial energy use broadly confirms this trend. The projected rate of increase in commercial energy consumption implicit in these forecasts is lower than that experienced between 1973 and 1985.[15] Increased supplies of biomass fuels (fuelwood and animal and crop wastes) will also be required. The World Energy Conference projects a 25 percent increase in biomass use. Population growth and economic development are the principal forces driving the rapid increase in energy use.

Population Growth

In many developing countries, fertility rates (the number of children expected to be born to a woman during the course of her life) have dropped dramatically over the past 20 years. Nevertheless, the population of the developing world continues to grow rapidly. Over 90 percent of world population growth is now occurring in the LDCs. At present, the population of the developing countries is about 4 billion, 77 percent of the world's population. Even assuming continued decreases in fertility rates, the population of these countries is projected to rise to 7 billion in 2025,[16] and could reach 10 billion in 2100, due to the large number of women of childbearing age. Developing countries would then account for 88 percent of the global population in 2100, and for virtually all of the increase in global population. The increase in population alone in developing countries would account for a 75 percent increase in their commercial energy consumption by 2025 even if per-capita consumption remained at current levels.

Economic Development

Securing higher living standards for the increasing population of the developing world implies high rates of economic growth. The World Energy Conference, for example, assumes in its "moderate" growth rate scenarios, an average annual gross rate of economic expansion of 4.4 percent to 2020, slightly lower than in the past. This would represent more than a fourfold increase in economic activity between now and 2020. Achieving such rates of growth will certainly not be easy, especially in light of the high levels of debt that have constrained economic growth in the 1980's, and increasing competition for foreign assistance from the countries of Eastern Europe; but failure to achieve high rates of growth could spell great hardship for the developing countries, as their populations are growing so rapidly.

The process of economic development that underlies improving living standards in developing countries involves a number of changes, including higher agricultural productivity, growth of manufacturing, construction of a modern public works infrastructure, urbanization, and increased transportation (table 1-5 shows the rapid increase in the road transport fleet). Higher standards of living also lead to expansion in the ownership of consumer appliances (table 1-6 illustrates saturation levels for some of the most widely used appliances). All of these changes have profound impacts on the amounts and types of energy used.

Commercial energy consumption typically rises faster than economic growth as the development process gets underway, and the share of commercial energy in total energy consumption grows as it takes the place of traditional biomass fuels. Even though the relative share of traditional fuels has declined, the absolute amounts consumed have continued to rise, by an estimated 2.5 percent per year.[17]

Despite the strong connection between commercial energy consumption and economic growth, there is evidence of considerable differences among developing nations in their energy intensity—the amount of commercial energy consumed relative to Gross National Product (GNP). There are examples of countries with similar per-capita incomes that consume quite different quantities of commercial energy. Some of these differences result from country-specific physical characteristics, but others are associated with differences in social and economic policies. Policies promoting heavy industry and high rates of urbanization contribute to high energy intensities. Similarly, the energy intensities of countries change over time. In several industrial countries energy intensities declined even before 1973 at a time when oil prices were falling, largely

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[15] World Energy Conference, *Global Energy Perspectives 2000-2020*, Montreal, 1989 (Paris: 1989) projects a threefold increase in consumption of commercial fuels in developing countries between 1985 and 2020. The Manne study projects a rise of 250 percent between 1985 and 2010 (see Alan S. Manne and Leo Schrattenholzer, "International Energy Workshop: Overview of Poll Responses," Stanford University International Energy Project, July 1989).

[16] Rudolfo A. Bulatao, Eduard Bos, Patience W. Stephens, and My T. Vu, *Europe, Middle East, and Africa (EMN) Region Population Projections, 1989-90 Edition* (Washington, DC: World Bank, 1990), table 9.

[17] World Energy Conference, *Global Energy Perspectives 2000-2020*, 14th Congress, Montreal 1989 (Paris: 1989).

Table 1-5—Passenger Fleet Annual Growth in Selected Countries (percent)

Country group	Passenger cars	Commercial vehicles	Two and three wheelers	Total
Developing countries:				
Cameroon	11.8	29.5	9.1	13.1
Kenya	3.2	3.7	4.0	3.3
Bolivia	8.6	24.5	6.9	11.6
Brazil	8.9	7.3	25.6	9.8
Thailand	8.8	4.4	9.5	8.8
India	8.2	11.2	25.4	18.4
China	41.6	14.8	44.9	29.8
Taiwan	16.2	5.4	10.3	11.0
Weighted average	10.0	11.4	19.1	13.9
Industrial countries:				
Japan	3.0	4.1	7.0	4.4
United States	2.4	3.5	-5.6	2.3
West Germany	3.3	0.4	-2.2	2.6
Weighted average	2.6	3.6	2.4	2.8

SOURCE: Fleet size and growth from Energy and Environmental Analysis, "Policy Options for Improving Transportation Energy Efficiency in Developing Countries," contractor report prepared for the Office of Technology Assessment, March 1990.

Table 1-6—Electric Appliance Ownership in Urban Areas (percent of households)

Country	Radio	TV	Fan	Washer	Iron	Cooker
China	39	66	45	2	1	—
Liberia	76	4	56	1	74	—
Guatemala	78	25	—	—	—	—
Manila	80	78	82	—	94	16
Malaysia	70	79	75	16	77	44
Hong Kong	90	91	96	34	87	91
Bangkok	—	96	—	5	—	84
Taipei	—	92	94	53	—	89

KEY: — information not available.

SOURCE: Jayant Sathaye and Stephen Meyers, "Energy Use in Cities of the Developing Countries," *Annual Review of Energy*, vol. 10, 1985, pp. 109-133, table 6.

due to improved technologies. After the 1973 and 1979 oil price shocks, the decline in energy intensities was experienced in all industrial countries. While the energy intensities of the developing countries continued to rise after 1973, the rise was less sharp than before. These experiences testify to some flexibility in commercial energy use. The current projections cited above, however, already incorporate assumptions about declining energy intensity in developing countries.

Energy Supply Constraints

The developing countries will face major difficulties in tripling energy supplies over the next 30 years. Significant obstacles include financial constraints, difficulties in increasing biomass fuel supplies, institutional and policy factors, and environmental impacts.

Financial Constraints

Commercial energy consists of both domestically produced and imported supplies. Many developing countries rely on imported oil for virtually all of their commercial energy needs. Further increases in energy imports will impose a heavy burden on limited foreign exchange resources, which may already be under pressure because of debt service payments (see table 1-7).

Funding the development of domestic energy supplies and infrastructure also poses problems. Energy supply facilities such as electricity generating stations and petroleum refineries are highly capital intensive, placing major demands on the scarce supplies of both domestic and foreign resources available for capital investment. Already, investments in the commercial energy supply sector (including electricity, oil and gas, and coal) represented in the 1980s over 30 percent of public

Table 1-7—Energy Imports, Debt Service, and Export Earnings for Selected Developing Countries,[a] 1987

Country	Energy imports as share of merchandise exports (percent)	Debt service as share of exports of goods and services (percent)	Energy imports and debt service as share of total exports 1987 (percent)
Low-income:			
Ethiopia	55	28.4	83.4
Tanzania	56	18.5	74.5
Madagascar	36	35.3	71.3
Rwanda	53	11.3	64.3
Benin	97	15.9	112.9
Kenya	39	28.8	67.8
Pakistan	26	25.9	51.9
Burma	5	59.3	64.3
Lower middle-income:			
Morocco	27	29.9	56.9
Jamaica	31	26.6	57.6
Turkey	31	31.7	62.7
Jordan	53	21.8	74.8
Syrian Arab Republic	40	16.5	56.5
Upper middle-income:			
Argentina	10	45.3	55.3
Algeria	2	49.0	51.0

[a] Includes all nations in which debt service and oil imports combined is greater than 50 percent of total exports.

SOURCE: World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), pp. 172-173 and 210-211.

investment budgets in a wide range of developing countries (see table 1-8), with the electric utility sector accounting for the lion's share. Despite these already large claims on capital resources, the current level of investment in the electricity sector may be inadequate. The World Bank estimates that investments of $125 billion annually (twice the current level) will be needed in developing countries to provide adequate supplies of electricity.[18] *This figure represents virtually the entire annual increase in the combined GNP of the developing countries.*

Finding the domestic and foreign resources needed to finance energy facilities has always posed major difficulties for developing countries. Current levels of domestic resource mobilization, often related to low levels of energy prices, are reported in many countries to fall short of the amounts needed for system expansion.[19] In the past, about one-half of all investments in energy supply have been provided by foreign sources,[20] but high levels of current debt in many developing countries and increasing fiscal difficulties in the industrial countries make it difficult for many developing countries to increase their borrowing from abroad.

Biomass Supply Constraints

It may be equally difficult to increase supplies of traditional biomass fuels. Despite rapid rates of urbanization in the developing world, almost two-thirds of the total populations in poor nations live in rural areas. These populations largely depend on biomass fuels to produce their energy, with some rural electrification where available, and small but vital quantities of petroleum products (for irrigation, lighting, and transport).

Demand for biomass fuels (largely fuelwood) will continue rising to meet the domestic needs of the urban and rural poor, rural industry, and in some cases, such as Brazil, modern industry. Overuse of biomass resources already contributes to environmental degradation (see below). Moreover, gathering traditional supplies of fuelwood is time-consuming, exhausting work frequently undertaken by women and children, who are thus diverted from other activities (education and farming) that could

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[18] U.S. Agency for International Development, *Power Shortages in Developing Countries: Magnitude, Impacts, Solutions, and the Role of the Private Sector* (Washington, DC: March 1988), p. 10.

[19] Lawrence J. Hill, *Energy Price Reform in Developing Countries: Issues and Options* (Oak Ridge, TN: Oak Ridge National Laboratory, August 1987).

[20] World Bank, *The Energy Transition in Developing Countries* (Washington, DC: 1983).

Table 1-8—Estimated Annual Energy Investment as a Percentage of Annual Total Public Investment During the Early 1980s

Over 40 percent	30-40 percent	20-30 percent	10-20 percent	0-10 percent
Argentina	Ecuador	Botswana	Benin	Ethiopia
Brazil	India	China	Egypt	
Colombia	Pakistan	Costa Rica	Ghana	
Korea	Philippines	Liberia	Jamaica	
Mexico	Turkey	Nepal	Morocco	
			Nigeria	
			Sudan	

SOURCE: Mohan Munasinghe, *Electric Power Economics* (London: Butterworths, 1990), p. 5.

eventually improve their productivity and living conditions. An estimated one-third of the population of developing countries now faces fuelwood deficits, and will increasingly rely on crop wastes and animal dung to meet their energy needs.

Institutional Constraints on Rapid Expansion in Energy Supplies

Over and above the capital constraints discussed above, a wide range of other factors, customarily defined as "institutional," currently impede commercial energy sector development. While definitions of institutional factors differ between observers, they are generally taken to be nontechnological, encompassing a variety of economic, organizational, and policy factors that affect the way technologies perform in operational settings.[21] Some of these factors (the worldwide increase in interest rates, for example) are outside the control of individual countries, but others are related to policies and procedures in the individual country.

The electricity supply system offers an example of the importance of institutional factors. In most countries of the developing world the electricity sector is government owned, reflecting the importance attached to electric power for meeting economic and social objectives, and in some cases, especially in small systems, the advantage of centralization for securing economies of scale and coordination in planning and operations. However, government ownership can lead to interference and loss of autonomy in day-to-day management of utility operations and therefore reduced efficiency. A recent World Bank report on the power sector in developing countries points out that:

> Such interference has adversely affected least cost procurement and investment decisions, hampered attempts to raise prices to efficient levels, mandated low salaries tied to civil service levels, and promoted excessive staffing. This in turn has resulted in inadequate management, the loss of experienced staff due to uncompetitive employment conditions and poor job satisfaction, weak planning and demand forecasting, inefficient operation and maintenance, high losses, and poor financial monitoring, controls and revenue collection.[22]

Manpower problems are exacerbated by the lack of standardization of equipment,[23] which makes the learning process more difficult. Another disadvantage of the multiplicity of equipment is the difficulty of maintaining adequate supplies of spare parts.

Pricing policies are frequently identified as a major institutional problem. Energy pricing policies vary in developing countries, reflecting differences in energy resource endowments and social and developmental policies. However, price controls on energy products, such as kerosene and some electricity prices, are a common feature in many countries. While low prices help to make energy more affordable, they can also result in a level of revenues inadequate to cover costs and finance future supply expansion. Many analysts have characterized this as a common problem in the electricity sectors of a wide range of developing countries.[24]

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[21] World Bank, *A Review of World Bank Lending for Electric Power* (Washington, DC: March 1988), p. 74.

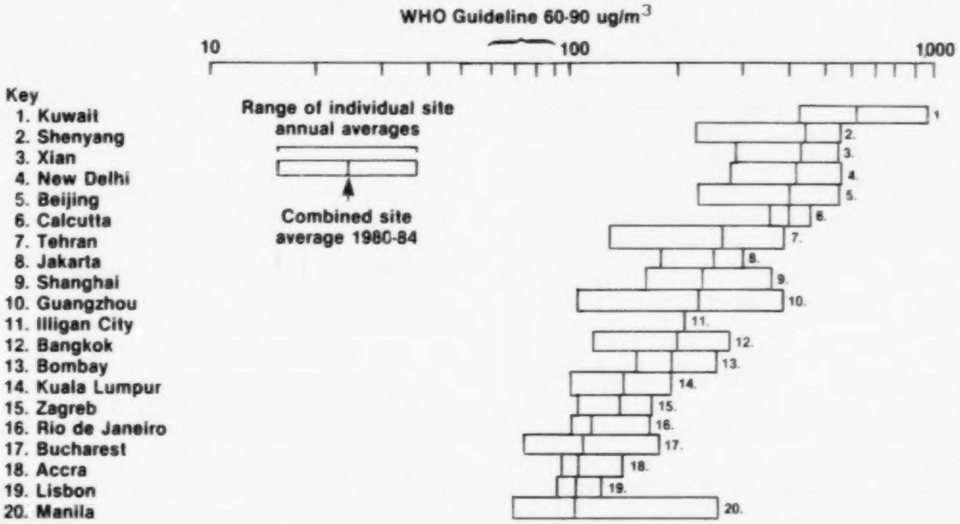
[22] Mohan Munasinghe, *Current Power Sector Issues in Developing Countries* (Washington, DC: World Bank, November 1986), p. 14.

[23] In Mali, for example, there are 40 diesel generator sets from 17 different manufacturers (see U.S. Agency for International Development, "Electric Power Utility Efficiency Improvement Study," draft core report, May 15, 1990).

[24] Hill, op. cit., footnote 19; and Donald Hertzmark, "Energy Efficiency and Energy Pricing in Developing Countries," OTA contractor report, June 1990.

Figure 1-5—Suspended Particulate Matter Levels in Selected Cities, 1980-84

Shown is the range of annual values at individual sites and the composite 5-year average for the city.



SOURCE: World Health Organization and United Nations Environment Fund, *Global Pollution and Health* (London: Yale University Press, 1987), figure 3.

Environmental Degradation in Developing Countries

Developing countries are experiencing accelerating rates of environmental degradation and pollution. While many factors contribute to environmental degradation, energy production and use play key roles, especially in urban environmental quality. Even at present levels of energy generation and use, the impacts on environmental quality are severe in many areas. Additional large increases in energy use will exacerbate the situation unless steps are taken to mitigate adverse environmental impacts. At the same time, energy is an essential input to such environmental control systems as sewage treatment.

The combustion of fossil fuels has led to levels of air pollution in cities of developing countries that are among the highest in the world (see figures 1-5 and 1-6). The transportation sector is the largest contributor to air pollution in many cities.[25] The combustion of oil or gas in stationary sources, such as electric generating units, factories, and households, also contributes through emissions of nitrogen oxides, particulates, sulfur dioxide, carbon dioxide, carbon monoxide, and hydrocarbons. The fossil fuel mix has an important impact on emission levels. Coal is the most deleterious of fossil fuels in terms of emissions per unit of useful energy provided, particularly when it is not burned in modern, well-operated plants.

In addition to the environmental damage caused by the combustion of fossil fuels, their production and transportation also impose environmental costs, such as disturbance of lands and aquifers from coal mining, and accidental leaks and spills during oil and gas production and refining. Air quality impacts include, for example, local air pollution from particulates and other emissions during coal mining preparation, and transport and the release of methane, during coal mining and natural gas production and transportation.

Non-fossil energy sources such as hydroelectric development also causes environmental damage. Dam construction often requires the clearing of lands for access routes and removal of construction material, with resulting soil degradation and erosion. Filling the reservoir floods large tracts of land, which usually means loss of agricultural land, human settlements, fish production, forests, wildlife

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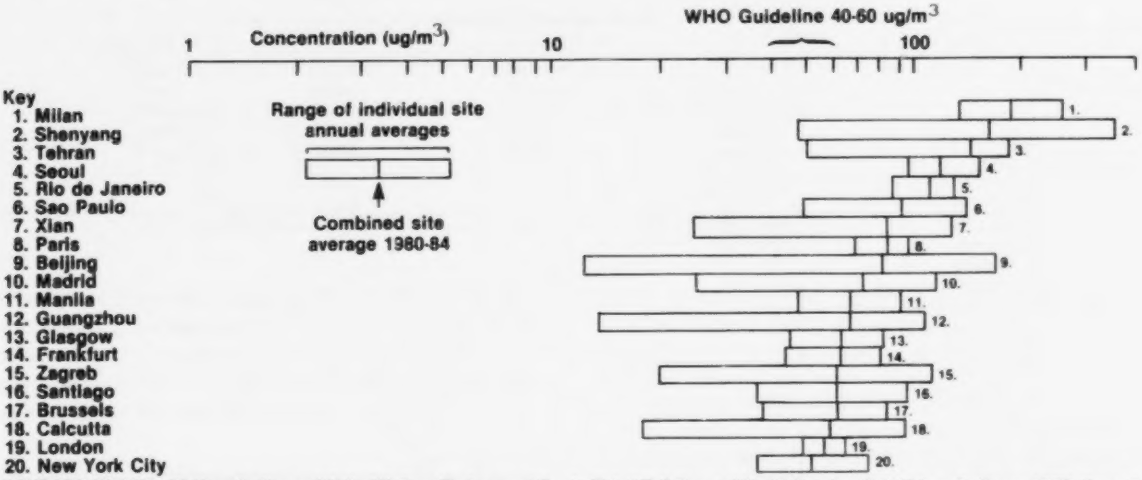
[25] In Indian cities, for example, gasoline-fueled vehicles—mostly two and three wheelers—are responsible for 85 percent of carbon monoxide and 35 to 65 percent of hydrocarbons, while diesel vehicles—buses and trucks—are responsible for over 90 percent no NO_x emissions. Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook 1988* (New Delhi, India: 1989), p. 250.

Figure 1-6—Sulfur Dioxide Levels in Selected Cities, 1980-84

Shown is the range of annual values at individual sites and the composite 5-year average for the city.



SOURCES: World Health Organization and United Nations Environment Fund, *Global Pollution and Health* (London: Yale University Press, 1987), figure 2.

habitat, and species diversity.[26] The dam and reservoir interrupt the free flow of surface water, affect water tables and groundwater flow, and disrupt downstream flows of water and nutrient-laden sediments. These environmental costs are all the more onerous if the lifespan of hydroelectric projects is reduced through heavier than expected siltation of reservoirs from deforested and/or degraded lands upstream.[27]

Burning biomass, the source of energy used by most of the developing world's population, also causes environmental degradation. Although the use of biomass for fuel is only one, and not the principal, cause of deforestation, it does add additional pressure on forest resources especially in arid or semi-arid regions where forest growth is slow and where there is a high population density or a concentrated urban demand for fuelwood, such as the African Sahel.[28]

When fuelwood is in short supply, rural populations turn to crop residues and dung for their fuel needs. To the extent that these forms of biomass would have been used as fertilizers, their diversion to fuel contributes to lowered soil productivity.[29]

Finally, biomass fuel combustion has a significant impact on air quality. Food is typically cooked over open fires or poorly vented stoves, exposing household members—particularly women and children—to high levels of toxic smoke. Similarly, in colder climates, homes in rural areas are often heated by open fires, with increased exposures to toxic smoke.[30]

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[26] For example, the reservoir Akosombo on the Volta in Ghana, with a land requirement of 8,730 km^2, approaches the size of countries such as Lebanon or Cyprus. See R.S. Panday (ed.), *Man-made Lakes and Human Health* (Paramaribo: University of Suriname, 1979).

[27] The Hirakud reservoir in India, for example, was expected to be productive for about 110 years, but now has an estimated productive lifetime of 35 years. U.S. Congress, Office of Technology Assessment, *Technologies To Sustain Tropical Forests*, OTA-F-214 (Washington, DC: U.S. Government Printing Office, March 1984), p. 43.

[28] Douglas F. Barnes, World Bank, "Population Growth, Wood Fuels, and Resource Problems in Sub-Saharan Africa," Industry and Energy Department Working Paper No. 26, March 1990; R.P. Moss and W.B. Morgan, "Fuelwood and Rural Energy Production and Supply in the Humid Tropics," United Nations University, Tycooly International Publishing, Ltd., Dublin, 1981; Daniel Finn, "Land Use and Abuse in the East Africa Region," *AMBIO*, vol. 12, No. 6, 1983, pp. 296-301. Dennis Anderson and Robert Fishwick, World Bank, "Fuelwood Consumption and Deforestation in African Countries," staff working paper No. 704, 1984.

[29] Organic matter in soils provides most of the nitrogen and sulfur and as much as half the phosphorus needed by plants. It helps the soil bind important minerals such as magnesium, calcium, and potassium that would otherwise be leached away. It buffers the acidity of soils, and it improves water retention and other physical characteristics. See Geoffrey Barnard and Lars Kristoferson, *Agricultural Residues as Fuel in the Third World*, Earthscan, International Institute for Environment and Development, Energy Information Program, technical report No. 4 (Washington, DC and London: Earthscan, 1985).

[30] Kirk R. Smith, *Biofuels, Air Pollution, and Health: A Global Review* (New York, NY: Plenum Press, 1987).

Greenhouse Gases and Developing Countries

Energy use in developing countries also contributes to increased emissions of greenhouse gases and associated global climate change. An international panel of scientific experts of the Intergovernmental Panel on Climate Change (IPCC)[31] recently concluded that:

> . . . emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the natural greenhouse effect, resulting on average in an additional warming of the Earth's surface.[32]

Based on current models, the panel predicts that, under a "business as usual" scenario, the global mean temperature will increase at a rate of about 0.3 °C per decade during the next century, a rate at least 10 times higher than any seen over the past 10,000 years.[33]

Atmospheric concentrations of CO_2 have increased by about 25 percent since preindustrial times, largely due to emissions from the burning of fossil fuels and from deforestation. In 1985, according to another IPCC working group, developing countries contributed about one-quarter (26 percent) of annual global energy sector CO_2 emissions.[34] Under the "business as usual" scenario, with expanding populations, rapidly increasing energy use, and assuming the absence of control measures, the developing country share would increase to 44 percent of annual energy sector emissions by 2025.[35]

The magnitude of CO_2 emissions from fossil fuel sources is fairly well known, but the contribution from deforestation, which is virtually all from developing countries, cannot be estimated accurately. This makes it difficult to calculate with confidence the developing country share of global annual and cumulative emissions for CO_2 and other gases. Estimates of CO_2 emissions from tropical deforestation differ by a factor of 4.[36] By various estimates, deforestation could be the source of between roughly 7 and 35 percent of total annual CO_2 emissions.

Despite uncertainties, it is safe to conclude that the developing countries already contribute a substantial part of current annual global CO_2 emissions, and that their share will increase in the future. But, because of their large and rapidly growing populations, *per-capita* CO_2 emissions in the developing countries will still remain much lower than in the countries of the industrial world. Developing countries also account for at least half of the global anthropogenic generation of two other important greenhouse gases, methane and nitrous oxide.

Developing and industrial countries would both be damaged by the anticipated impacts of climate change. In addition to increases in mean global temperature, other major effects of global climate change would include increases in sea level[37] and shifts in regional temperature, wind, rainfall, and storm patterns. These effects in turn would submerge some low-lying coastal areas and wetlands, threaten buildings and other structures in these areas, and increase the salinity of coastal aquifers and estuaries. Such changes would disrupt human communities and aquatic and terrestrial ecosystems, and affect food production and water availability. A number of developing countries would be especially vulnerable to rising sea levels through threats to coastal communities and ecosystems, increased vulnerability to storm damage, and inundation of low-lying arable lands.[38] The adverse effects of climate change would exacerbate the impacts of increased populations in Asia, Africa, and small island nations of the Caribbean, Indian, and Pacific Oceans.[39] The timing, severity, and extent of these potential impacts remain uncertain.

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[31] The Intergovernmental Panel on Climate Change (IPCC) is an international task force created by the World Meteorological Organization and the United Nations Environment Program. Initiated in 1987, this body focuses on analyzing current information available on climate change issues and devising strategies to address climate change.

[32] Intergovernmental Panel on Climate Change, "Policymakers Summary of the Scientific Assessment of Climate Change: Report to IPCC from Working Group I," June 1990, p. i.

[33] Id., at p. ii. This would mean an increase over the preindustrial global average temperature of 2 degrees centigrade by 2025 and 4 °C by 2090. This best estimate prediction has an uncertainty range of 0 2 to 0.5 °C per decade. This was based on projections derived from another working group that emissions of CO_2 could grow from approximately 7 billion tonnes of carbon (BtC) in 1985 to between 11 and 15 BtC in 2025. Methane emissions were projected to increase from 300 teragrams in 1985 to 500 teragrams by 2025.

[34] Intergovernmental Panel on Climate Change, Working Group III (Response Strategies Working Group), "Policymakers' Summary of the Formulation of Response Strategies: Report Prepared for IPCC," Executive Summary, p. 10, table 2, June 1990.

[35] OTA calculation based on 2030 High Emissions—Lower Growth Scenario, tables A-21 and A-193 in Intergovernmental Panel on Climate Change, "Emissions Scenarios Prepared by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change," Appendix Report of the Expert Group on Emissions Scenarios (RSWG Steering Committee, Task A), April 1990.

[36] IPCC, "Policymaker's Summary of the Formulation of Response Strategies: Report Prepared for IPCC by Working Group III," June 1990, p. 5. Estimates of CO_2 emissions from deforestation and land use changes (including wood fuel) were 0.6 to 2.5 PtC in 1980 according to a report prepared for the IPCC Working Group 1. "Scientific Assessment of Climate Change: Peer Reviewed Assessment for WG1 Plenary Meeting, May 1990," Apr. 30, 1990, p. 1-9. More recent evidence from selected countries would indicate deforestation rates now are higher than they were in 1980. Estimates of CO_2 emissions in 1987 were 5.7 +0.5 PtC from fossil fuel burning and total emissions were of 7 +1.1 PtC.

[37] The IPCC working group predicted an average rate of global mean sea level rise of about 6 cm per decade over the next century—20 cm by 2030 and 65 cm by the end of the century (with significant regional variations). This predicted increase is due primarily to thermal expansion of the oceans and melting of some land ice.

Prospects for Efficiency Improvements in Energy Production and Use

Increasing energy supplies in the "business as usual" mode that underlies the conventional projections thus poses formidable challenges. This unfortunate fact suggests that alternative approaches for providing the vital energy services needed for rapid economic and social development should be investigated, focusing on efficiency improvements.

OTA examined the following energy-related services: cooking, lighting, and appliances in the residential and commercial sectors; process heat and electrical and mechanical drive in industry and agriculture; and transportation (see ch. 3). For the developing countries as a whole, the largest energy end use markets are residential/commercial and industry, which together account for roughly 85 percent of the energy used by final consumers, including traditional energy. Considerable differences exist, however, among developing nations. In Africa, the residential/commercial sector constitutes a particularly high share (mostly in the form of biomass fuels for cooking), while industry's share is quite low. In Latin America, transportation accounts for an exceptionally high share of the total, whereas its share in India and China is quite low.

Industrial process heat and cooking are the largest energy services, each accounting for about one third of all energy consumed (commercial plus biomass) in developing countries. This pattern of energy use contrasts with the United States, where transportation and space conditioning are the highest (although in the United States process heat is a major user as well). Much of the energy used for residential cooking and process heat in the developing countries is consumed in China and India. Together their consumption of energy for cooking and industrial process heat accounts for over 40 percent of all cooking and process heat energy used by developing countries, and for well over one-quarter of all the energy consumed in developing countries.

A wide range of technologies are currently used to provide energy services in developing countries. For example, cooking technologies include stoves using fuelwood, charcoal, kerosene, liquid petroleum gas, natural gas, and electricity, all with different characteristics. These technologies vary widely in their *energy efficiency*. In an open fire, for example, only about 15 percent of the energy contained in fuelwood goes into cooking. In contrast, in a "modern" gas stove about 60 percent of the energy contained in the gas is used in cooking. The wide range of efficiencies in the current stock of stoves suggests opportunities for increasing efficiencies of the stock and therefore providing more cooking services with less energy.

There are also differences in efficiencies in providing energy services in the industrial sector—industrial process heat and electric and mechanical drive. The two largest developing country energy consumers, India and China, currently rely on several technologies that are a generation or more behind the state of the art, and are much less energy-efficient than technologies now being used in the United States and other countries. Integrated iron and steel plants in China and India, for example, use twice as much energy per ton of crude steel produced as integrated plants in the United States and Japan. Lower efficiencies are also frequently observed in the transportation sector.

An analysis of the energy supply industry in developing countries similarly indicates much lower operating efficiencies than in the industrial countries. In electricity generation, for example, thermal power plants frequently operate far below design capacity and efficiency. Transmission and distribution losses (including unaccounted for losses, unmetered use, etc.) are frequently over 15 percent, substantially higher than losses in industrial country systems.[40] Refineries also operate at much lower efficiencies.

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[38] Intergovernmental Panel on Climate Change, "Policymakers' Summary of the Potential Impacts of Climate Change: Report from Working Group II to the IPCC," May 1990, p. 8.

[39] J.D. Milliman et al., "Environmental and Economic Implications of Rising Sea Level and Subsiding Deltas: The Nile and Bengal Examples," *AMBIO*, vol. 18, pp. 340-345, 1989.

Energy supplies in many developing countries are unreliable, imposing a heavy economic burden. In India, for example, losses sustained by industry due to unreliable electric power supplies in recent years are estimated to represent 2 percent of annual GNP, not including losses in agriculture or losses and inconvenience experienced by residential and commercial users. Similar losses have been estimated for Pakistan. Furthermore, electricity supplies in many countries are of poor quality, discouraging the use of efficient technologies that are critically dependent on high-quality energy supplies.

In characterizing important parts of the energy system as "inefficient," however, it should be realized that in many cases users and producers are acting logically given the framework of resources, incentives, and disincentives within which they make their decisions. One of the reasons that poor households use fuelwood inefficiently is that they lack the financial means to buy more efficient cooking systems. Industrial users must cope with antiquated machinery and erratic fuel supplies of uncertain quality. On the supply side, the record of "poor" performance reflects many factors: poor repair and maintenance, unavailability of spare parts, low fuel quality, older equipment, unsatisfactory management, lack of skilled workers, problems of reaching dispersed populations served by inadequate transport systems, and inappropriate pricing and allocation systems.

The existence of wide differences between operational efficiencies in reasonably standardized operations (e.g., cooking, steelmaking, electricity generation, and petroleum refining), both among developing countries and between the developing and industrial countries, suggests that dramatic improvements in efficiencies are possible. However, the importance of factors other than technology must be recognized for the role they play in improving efficiencies. The policy environment in particular is crucial to the adoption of new technologies.

More efficient ways of providing energy services for development, including both technologies and the institutional and policy mechanisms determining their rate of adoption, will be presented in a later report of this OTA assessment. Attention will also be paid to the energy implications of different development strategies. Some development strategies are associated with high energy use. But developing countries at the beginning of the development process may be able to capitalize on technology to develop toward modern economies without the high energy growth that earlier characterized the path to industrialization.

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[40] In the United States, for example, transmission and distribution losses in dense urban service areas are between 6 and 7 percent and in rural service areas nearer 9 to 10 percent.

Appendix 1A—Economic, Social and Energy Indicators for Developing Countries

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	GNP per capita 1987 ($)	GNP per capita ($ppp)	Share of agriculture in total production 1987 (%)	Urban population as share of total 1987 (%)	Life expectancy at birth 1987 (yrs)	Infant mortality 1987 (per 1,000 live births)	Population per physician 1984	Percent of age group in secondary education 1986 (%)	Consumption of traditional fuels per capita 1986 (GJ)	Consumption of commercial fuels per capita 1986 (GJ)	Total energy consumption per capita 1986 (GJ)	Share of traditional fuels in total 1986 (%)	Net energy imports as a share of commercial energy consumption 1986 (%)	Energy imports as a share of merchandise exports 1987 (%)	Debt service as a share of exports of goods and services 1987 (%)
Low-income countries															
Average	280 w	—	33 w	24 w	54 w	103 w	13,550 w	9 w	—	—	—	—	—	16 w	21.9 w
1 Ethiopia	130	304	42	12	47	154	77,360	12	8.19	0.67	8.86	92	100	55	28.4
2 Bhutan	150	—	51	5	48	126	23,310	4	22.31	0.00	22.31	100	100	—	—
3 Chad	150	254	43	30	46	132	38,360	6	5.85	0.57	6.42	91	100	—	3.9
4 Zaire	150	200	32	38	52	98	—	—	8.68	3.01	11.69	74	x	2	12.8
5 Bangladesh	160	646	47	13	51	119	6,730	18	2.46	0.03	2.49	99	40	21	24.2
6 Malawi	160	—	37	13	46	150	11,560	4	7.97	1.77	9.75	82	100	10	23.3
7 Nepal	160	526	57	9	51	128	32,710	25	8.64	0.85	9.49	91	92	31	9.7
8 Lao PDR	170	—	—	17	48	110	1,360	19	10.00	3.42	13.42	75	75	—	—
9 Mozambique	170	528	50	23	48	141	37950	7	9.59	0.89	10.48	92	100	—	—
10 Tanzania	180	291	61	29	53	106	—	3	9.29	1.26	10.54	88	100	56	18.5
11 Burkina Faso	190	359	38	8	47	138	57,180	6	7.83	0.72	8.55	92	100	7	—
12 Madagascar	210	370	43	23	54	120	10,000	36	5.87	1.19	7.06	83	100	36	35.3
13 Mali	210	337	54	19	47	169	25,390	7	6.03	0.64	6.67	90	100	32	9.9
14 Burundi	250	338	59	7	49	112	21,120	4	7.20	0.60	7.80	92	100	8	38.5
15 Zambia	250	579	12	53	53	80	7,100	19	13.19	19.58	32.78	40	33	11	13.5
16 Niger	260	320	34	18	45	135	38,770	6	5.44	1.47	6.91	79	100	9	33.5
17 Uganda	260	319	76	10	48	103	21,900	—	7.01	1.15	8.15	86	100	17	19.5
18 Somalia	290	348	65	36	47	132	16,090	12	7.72	2.63	10.35	75	100	9	8.3
19 Togo	290	489	29	24	53	94	8,720	21	1.88	1.56	3.44	55	100	8	14.2
20 Rwanda	300	388	37	7	49	122	34,680	3	8.59	1.25	9.84	87	100	53	11.3
21 Sierra Leone	300	441	45	26	41	151	13,630	—	20.00	1.84	21.84	92	100	10	—
22 Benin	310	531	46	39	50	116	15,940	16	9.77	1.40	11.16	88	x	97	15.9
23 Central African Rep.	330	436	41	45	50	132	23,070	13	10.74	0.74	11.48	94	100	1	12.1
24 Kenya	330	603	31	22	58	72	10,100	20	14.43	2.94	17.38	83	100	39	28.8
25 Sudan	330	562	37	21	50	108	10,110	20	8.31	2.12	10.43	80	100	38	6.8
26 Pakistan	350	1,165	23	31	55	109	2,900	18	2.19	8.49	10.67	20	39	26	25.9
27 Haiti	360	591	—	29	55	117	7,180	18	9.51	1.80	11.31	84	93	16	7.0
28 Lesotho	370	795	21	19	56	100	18,610	22	0.00	0.00	0.00	—	—	—	4.4
29 Nigeria	370	565	30	33	51	105	7,960	—	8.32	4.82	13.14	63	x	310.0	
30 Ghana	390	361	51	32	54	90	14,890	35	6.10	5.07	11.18	55	100	14	19.2
31 Sri Lanka	400	1,491	27	21	70	33	5,520	66	4.76	4.82	9.57	50	87	25	19.2
32 Yemen, PDR	420	1,038	16	42	51	120	4,340	—	0.00	15.22	15.22	0	70	—	38.2
33 Mauritania	440	539	37	38	46	127	12,110	15	0.00	4.21	4.21	0	100	8	18.2
34 Indonesia	450	1,269	26	27	60	71	9,460	41	7.70	8.47	16.17	48	x	13	27.8
35 Liberia	450	539	37	42	54	87	9,240	—	17.39	4.78	22.17	78	100	11	2.5
37 Burma	—	562	—	24	60	70	3,740	—	4.07	2.65	6.72	61	1	5	59.3
38 Guinea	—	—	—	24	42	147	57,390	9	5.69	2.46	8.15	70	100	—	—
39 Kampuchea, Dem.	—	—	—	—	42	—	—	—	—	—	—	87	100	—	—
40 Viet Nam	—	—	—	21	66	46	1,000	43	3.40	3.52	6.92	49	20	—	—
China and India															
Average	300 w	—	30 w	33 w	65 w	62 w	1,840 w	25 w	—	—	—	—	—	5 w	10.7
41 China	290	1,489	31	38	69	32	1,000	42	1.70	21.15	22.00	7	x	2	7.1
42 India	300	775	30	27	58	99	2,520	35	3.01	8.34	11.36	27	14	17	19.9

Lower middle-income countries															
Average	1,200 w	—	—	51 w	64 w	61 w	3,330 w	51 w	—	—	—	—	—	10 w	21.7
43 Senegal	520	754	22	37	48	128	13,450	13	5.71	3.57	9.29	62	100	24	21.4
44 Bolivia	580	1,106	24	50	53	110	1,540	37	2.39	10.90	13.28	18	x	2	22.1
45 Zimbabwe	580	954	11	26	58	72	6,700	46	7.89	21.67	29.56	27	23	6	23.2
46 Philippines	590	1,352	24	41	63	45	6,700	68	5.51	8.41	13.92	40	93	21	23.2
47 Yemem Arab Rep.	590	—	28	23	51	116	6,270	15	0.00	0.00	0.00	—	70	—	24.8
48 Morocco	610	1,284	19	47	61	82	15,610	34	0.56	9.36	9.91	6	100	27	29.9
49 Egypt, Arab Rep.	680	1,080	21	48	61	85	790	66	0.82	21.48	22.30	4	x	5	18.5
50 Papua New Guinea	700	1,414	34	15	54	62	6,160	—	15.41	9.19	24.59	63	—	10	13.0
51 Dóminican Rep.	730	1,702	17	58	66	65	1,760	47	4.48	13.58	18.06	25	100	37	—
52 Cote d Ivoire	740	941	36	44	52	96	—	20	7.57	6.76	14.32	53	100	11	19.6
53 Honduras	810	915	22	42	64	69	1,510	36	10.85	7.23	18.09	60	92	15	23.0
54 Nicaragua	830	1,857	21	58	63	62	1,500	42	9.43	10.00	19.43	49	97	33	—
55 Thailand	850	1,896	16	21	64	39	6,290	29	10.56	12.95	23.51	45	59	15	13.6
56 El Salvador	86C	1,267	14	44	62	59	2,830	24	11.02	8.57	19.59	56	100	14	19.4
57 Congo,People'sRep.	870	917	12	41	59	73	8,140	—	8.50	12.50	21.00	40	x	5	18.6
58 Jamaica	940	1,733	6	51	74	18	2,060	—	2.08	32.50	34.58	6	100	31	26.6
59 Guatemala	950	1,597	—	33	62	59	2,180	20	9.88	5.95	15.83	62	93	16	24.9
60 Cameroon	970	1,180	24	46	56	94	—	23	8.53	9.91	18.44	46	x	1	15.9
61 Paraguay	990	1,869	27	46	67	42	1,460	30	12.82	11.03	23.85	54	69	10	21.3
62 Ecuador	1,040	2,361	16	55	65	63	830	55	6.87	22.53	29.39	23	x	3	20.7
63 Botswana	1,050	1,987	3	21	59	67	6,910	31	0.00	0.00	0.00	—	—	6	3.7
64 Tunisia	1,180	2,023	18	54	65	59	2,150	39	3.55	19.74	23.29	15	15	15	26.9
65 Turkey	1,210		17	47	64	76	1,380	44	7.91	26.92	34.83	23	—	31	31.7
66 Colombia	1,240	2,612	19	69	66	46	1,190	56	6.00	28.31	34.31	17	x	2	33.4
67 Chile	1,310	3,708	—	85	72	20	1,230	70	4.64	34.16	38.80	12	54	9	21.1
68 Peru	1,470	2,333	11	69	61	88	1,040	65	4.16	19.21	23.37	18	x	1	12.5
69 Mauritius	1,490	1,751	15	42	67	23	1,900	51	19.00	13.00	32.00	59	100	7	6.1
70 Jordan	1,560	2,102	9	66	66	44	1,140	—	0.00	29.21	29.21	0	100	53	21.8
71 Costa Rica	1,610	2,712	18	45	74	18	960	42	21.92	23.08	45.00	49	78	12	12.1
72 Syrian Arab Rep.	1,640	2,864	27	51	65	48	1,260	60	0.00	35.98	35.98	0	x	40	16.5
73 Malaysia	1,810	3,204	—	40	70	24	1,930	54	4.79	31.76	36.55	13	100	4	14.3
74 Mexico	1,830	3,987	9	71	69	47	1,240	55	2.94	49.45	52.39	6	x	1	30.1
75 South Africa	1,890	3,948	6	57	60	72	—	—	4.20	95.20	99.40	4	x	0	—
Upper middle-income countries															
Average	2,710 w	—	—	66 w	67 w	50 w	1,170 w	59 w	—	—	—	—	—	12 w	25.8 w
78 Brazil	2,020	3,164	11	75	65	63	1,080	36	17.82	32.76	50.58	35	46	17	26.7
79 Uruguay	2,190	3,737	13	85	71	27	510	71	10.33	38.00	48.33	21	92	15	24.4
81 Panama	2,240	2,920	9	54	72	23	980	59	8.70	26.52	35.22	25	—	29	6.5
82 Argentina	2,390	3,640	13	85	71	32	370	74	4.18	57.36	61.54	7	10	10	45.3
84 Algeria	2,680	2,133	12	44	63	74	2,330	54	0.74	36.41	37.14	2	x	2	49.0
85 Korea, Rep.	2,690	3,381	11	69	69	25	1,170	95	1.47	53.90	55.37	3	88	13	21.9
86 Gabon	2,700	3,313	11	43	52	103	2,790	27	22.73	38.18	60.91	37	x	1	5.1
88 Venezuela	3,230	3,723	6	83	70	36	700	46	1.26	106.17	107.43	1	x	0	22.6
90 Trinidad and Tobago	4,210	4,544	4	67	70	20	980	76	2.50	222.50	225.00	1	x	4	—
91 Libya	5,460	—	—	67	61	82	690	—	1.22	20.98	22.20	5	x	—	—
92 Oman	5,810	7,792	3	10	55	100	1,700	35	0.00	243.08	243.08	0	x	2	—
High-income economies															
Average	14,430 w	—	—	77 w	76 w	10 w	470 w	92	—	—	—	—	—	11 w	—
110 Germany, Fed. Rep.	14,400	9,739	2	86	75	8	380	72	0.6	185.39	186	0	58	7	—
116 Japan	15,760	10,959	3	77	78	6	660	96	0.05	128.94	129	0	96	17	—
119 United States	18,530	12,787	2	74	75	10	470	100	4.88	305.11	310	1	15	19	—

—not available or not applicable.

w = weighted average.

x = exporter.

SOURCE: Columns 1, 3, 4, 5, 6, 7, 8, 13, 14, and 15 from World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), World Development Indicators, various tables. Column 2 from R. Summers et al., "A New Set of International Comparisons of Real Product and Price Levels Estimates for 130 Countries, 1950-1985," *Review of Income and Wealth*, Series 34, No. 1, March 1988. Columns 9, 10, 11, and 12 from United Nations, *Energy Statistics Yearbook 1986* (New York, NY: United Nations, 1988), table 4, normalized by population from World Development Indicators.

Chapter 2

Energy and Economic Development

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Chapter 2

Energy and Economic Development

Introduction and Summary

This chapter examines the two-way linkage between energy and economic development in developing countries—how the process of economic development impacts energy, and how, in turn, developments in the energy sector can affect economic growth.

In the course of economic development, commercial energy consumption is observed to increase faster than economic activity. There are a number of reasons for this: the growth of mechanized agriculture and manufacturing, the construction of a modern infrastructure, urbanization, increased transportation of goods and services, rapid expansion in ownership of consumer appliances, and the substitution of commercial for traditional fuels. The absolute amount of traditional energy consumed also continues to rise, although its share of total energy consumption falls.

In the years to come, high rates of economic growth will be needed in developing countries to provide their rapidly growing populations with improved living standards. If current trends in energy and economic growth continue, commercial energy consumption in the developing countries could more than double over the next 40 years according to most projections. Supplies of biomass fuels would also need to increase substantially to meet the needs of growing rural populations and the urban poor.

This prospect raises a dilemma. On the one hand, increases in energy supplies on this scale could severely strain financial resources in the developing countries. The energy sector absorbs a large share of available foreign exchange and capital investment. Consequently, energy supply policies have far-reaching impacts on other development priorities. In many developing countries, financial resources may not be adequate to increase commercial energy supplies on the scale projected above.

On the other hand, inability to supply needed energy can frustrate economic and social development. Already in many countries, the unreliability and poor quality of energy supplies lead to major costs to the economy through wasted materials, stoppage of operations, and investment in standby equipment.

Energy prices are a key factor in the development of a country's energy supply infrastructure, through their impacts on the amount of energy used in the economy, the technologies adopted, and, in some cases, the direction of industrial development. Energy prices in developing countries are typically subject to price regulation throughout the distribution chain. The average level of energy prices, particularly in the electricity sector, are reported to be too low in many countries to ensure the sector's financial viability.

Although commercial fuels attract the most policy attention, two-thirds of the developing world's population live in rural areas with low standards of living based on low-resource farming. This population has little access to commercial fuels and relies largely on traditional sources of energy, gathered and consumed locally, and animal and human energy, often used at very low efficiencies. The main form of traditional energy used is wood, an increasingly scarce and unsustainable resource. This imposes a special hardship on those—mainly women and children—responsible for gathering it. Dung and crop wastes, the other forms of energy widely used for cooking when wood is not available, have alternative uses as soil nutrients.

Economic Development and Its Impact on Energy

The pace of economic growth and level of economic activity have major impacts on the energy sector. From 1965 to 1987, for example, the economies of the developing countries grew at an annual average of 5.3 percent, and their consumption of commercial energy grew by just over 6 percent.[1] These energy growth rates were higher than those in the industrial countries over the same period. As a result, the developing countries' share of global commercial energy consumption also rose—from 17 percent in 1973 to 23 percent in 1987.[2] High rates of economic growth will continue to be needed in the developing world to provide the rapidly growing population with improved living standards.

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[1] World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), pp. 167 and 173.

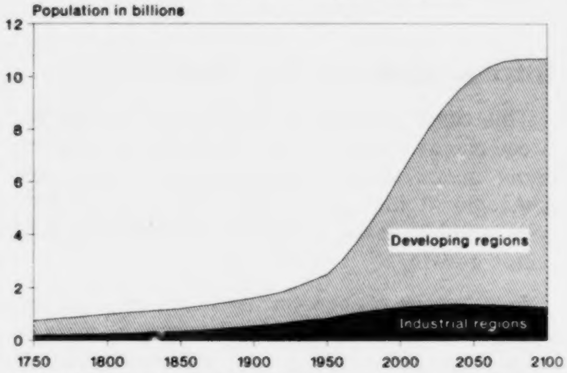
Rising Populations

The past two centuries have witnessed sharply accelerated growth in the global population (see figure 2-1). The largest additions to global population have been in the developing countries and have occurred primarily in the past 50 years (see figure 2-2). Box 2-A discusses factors affecting population growth.

Although current projections of global population growth over the next 35 years differ (see figure 2-3), there is consensus on several major points:

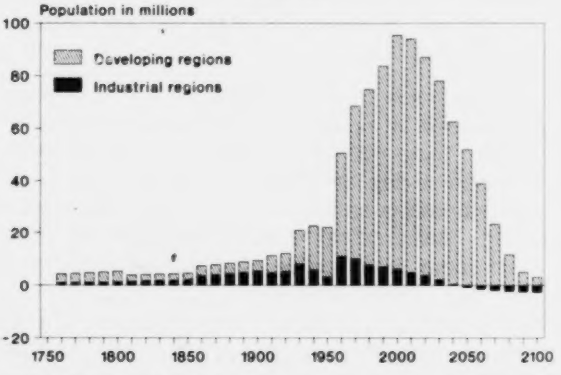
- The world's population is projected to increase despite assumptions of continued declines in fertility rates. The rate of increase in global population, while lower than in the past, still represents a large increase in numbers of people. World Bank estimates,[3] which are similar to both the United Nations medium projection and the U.S. Department of Agriculture projection, project an increase in global population from 5.3 billion in 1990 to 8.4 billion in 2025, an increase of 3.1 billion.
- Virtually all of the increase will come from the developing countries. According to the World Bank projection, for example, population growth in the industrial countries—i.e., nations in the Organization for Economic Cooperation and Development (OECD), the U.S.S.R., and Eastern Europe—is expected to add only about 125 million, or about 4 percent of the global increase (see figure 2-4). The population of the developing countries is estimated to rise from its present level of 4.1 billion to 7.1 billion in 2025, increasing their share of world population from 77 to 88 percent (see figure 2-4).
- Population growth in China is projected to be quite moderate, as current low rates of growth are assumed to be maintained. Projections of China's population growth are critical because of its large share of the global total.
- According to World Bank projections, the biggest increases in population are predicted to come from Africa and Asia, which will account for 30 and 58 percent respectively of the total global increase. In Asia the large addition to population derives from the existing large population base; rates of population growth are relatively low. In Africa, on the other hand, the primary cause is the rapid increase in population that, despite the relatively low population, increases its share of the total population from a current 12 percent to 19 percent in 2025.

Figure 2-1—World Population Growth, 1750-2100 in Industrial and Developing Regions



SOURCE: Thomas Merrick, Population Reference Bureau, "World Population in Transition," *Population Bulletin*, vol. 41, No. 2, April 1986, update based on United Nations 1989 projections.

Figure 2-2—Average Annual Increase in Population Per Decade in Industrial and Developing Regions, 1750-2100



SOURCE: Thomas Merrick, Population Reference Bureau, "World Population in Transition," *Population Bulletin*, vol. 41, No. 2, April 1986, update based on United Nations 1989 projections.

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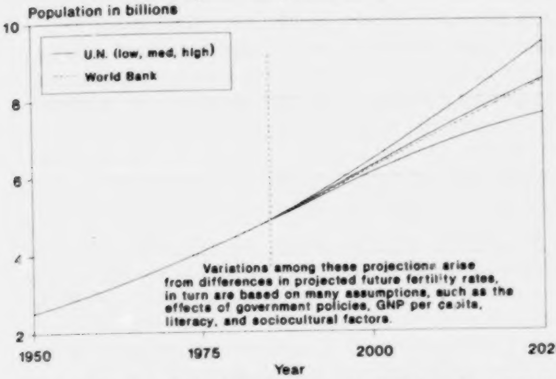
[2] World Energy Conference, *Global Energy Perspective 2000-2020* 14th Congress, Montreal 1989 (Paris: 1989), Table 2.

[3] Rodolfo A. Bulatao, Eduard Bos, Patience Stephens, and My T. Vu, *Europe, Middle East, and Africa (EMN) Region Population Projection: 1989-90 Edition*, Population and Human Resources Department, working paper 328 (Washington, DC: World Bank), November 1989, table 5.

Figure 2-3—Historical and Projected Global Population, 1950-2025



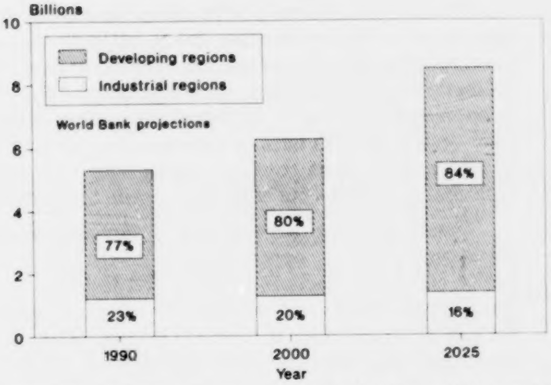
SOURCE: Office of Technology Assessment, 1990, based on data in United Nations, *World Population Prospects 1988* (New York, NY: United Nations, 1989); Rodolfo Bulatao et al., *Europe, Middle East, and Africa (EMN) Region Population Projections, 1989-90 Edition*, World Bank, Population and Human Resources Department, Washington, DC, working paper series 328, November 1989.

Though there will no doubt be some unforeseen divergence from these population paths (changes in fertility rates are difficult to predict; the impact of the AIDS epidemic in Africa on fertility rates and population growth is unknown), it is clear that there will be a large increase in the world's population in the decades ahead, accompanied by a powerful upward pressure on energy consumption. Even with no increase in per-capita energy consumption, the predicted rise in the global population by 2025 implies a 75 percent increase in total commercial energy consumption.

Higher Living Standards

The major development challenge is to provide higher standards of living for the rapidly rising populations of the developing world. This task is all the more urgent because of the declining levels of per-capita income in many of the countries of Latin America and Africa in recent years. Given the projected rise in developing country populations—an annual average of about 1.6 percent over the next 35 years—a rise in average per-capita incomes of, say, 3 percent per year implies economic growth rates of around 4.6 percent annually.[4]

Figure 2-4—Projected Shares of Global Population, 2000 and 2025



SOURCE: Rodolfo Bulatao et al., *Europe, Middle East, and Africa (EMN) Region Population Projections, 1989-90 Edition*, World Bank, Population and Human Resources Department, Washington, DC, working paper series 328, November 1989.

It may not be easy to achieve such rates of growth. The current indebtedness of many developing nations has added to the already difficult tasks of economic management, and threatens to jeopardize prospects of attaining even modest improvements in standards of living. The foreign debt of developing countries increased rapidly in the 1970s and 1980s and in early 1989 was estimated at about $1.3 trillion.[5] As a result of this increase and the rise in interest rates, debt service as a share of total exports of goods and services is now double what it was in the early 1970s.[6]

Changes in Energy Consumption With Economic Development

The economic expansion necessary to achieve higher standards of living for the increasing population of the developing world would be expected to

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[4] The World Energy Conference "moderate" growth rate projection is based on annual economic growth rates of 4.4 percent. Average economic growth rates of 5.3 percent annually are assumed in the series of projections in Alan S. Manne and Leo Schrattenholzer, "International Energy Workshop: Overview of Poll Responses," Stanford University International Energy Project, California, July 1989. The Intergovernmental Panel on Climate Change, "Appendix Report of the Expert Group on Emissions Scenarios (Response Strategies Working Group Steering Committee, Task A)," April 1990, assumes high economic growth rates for the different developing regions of 4 to 5 percent annually, and 2.2 to 3.0 percent annually for the low-growth case.

[5] United Nations Development Programme, *Human Development Report 1990* (New York, NY: Oxford University Press, 1990), p. 79.

[6] These principal and interest repayments are now much higher than new disbursements of long-term debt to developing countries. The net transfer or outflow of resources from the developing countries amounted to $38 billion in 1987, compared with a net inflow of $35 billion in 1981. See World Bank, *World Development Report 1989* (Washington, DC: Oxford University Press, 1989), p. 18.

Box 2-A—Factors Affecting Population Increase

Rates of population growth are determined by the balance between birth and death rates. Historically, death rates were the first to decline, due to improvements in nutrition and sanitation, and medical advances such as vaccines. If death rates decline, but birth rates remain the same, population increases. This is what happened in the presently developed world from 1750 to about 1900. Around that time, however, birth rates started to fall, resulting in an overall reduction in the rate of population increase. This process, the lagged adjustment of birth rates to the prior decline in death rates, is known as the "demographic transition." In the developing world, the demographic transition is far from complete: death rates have fallen dramatically—though they are still higher than in the industrial countries—but birth rates remain high, leading to a continued rapid rate of increase in total population.[1]

Future trends in population will similarly depend on the balance between death and birth rates. For the developing countries, opportunities still exist to reduce death rates through improvements in medicine and public health, and further declines are likely and desirable. On the side of birth rates, there is much greater uncertainty over future trends. Birth rates are falling in the developing countries, from 41 crude births per thousand population in the mid-1960s to 30 per thousand at present. Birth rates in the developing countries, however, are still well above death rates, and more than twice the birth rates in the industrial countries (currently 13 per thousand).

The number of births depends on three factors: fertility rates, the age structure of the population, and the size of the population base.

The fertility rate is defined as "the number of children that would be born to a woman if she were to live to the end of her childbearing years and bear children at each age in accordance with prevailing age-specific fertility rates." Fertility rates in developing countries have fallen steadily, and in some cases sharply, in recent years. For the developing countries as a whole, they fell from 6.1 in 1965 to 4 in 1987, with particularly sharp declines in China and India, Sri Lanka, Korea, and several Latin American countries. Despite this drop, they are still much higher than in the industrial countries. There are, however, exceptions to this declining trend; fertility rates have not changed in sub-Saharan African countries, and in some of these countries the rates appear to have risen.

Fertility rates are projected to continue declining until the end of the century, when they would be 3.3 compared with the current 4. While this assumption seems reasonable in the light of historical trends, the determinants of family size are not clearly known, and there is inevitably some degree of uncertainty over such assumptions. Broadly speaking, fertility rates decline as levels of economic and social development and urbanization rise, women's education improves, and knowledge about family planning spreads. The connections between these factors are not well-established, however, as they are highly correlated, and it is therefore difficult to disentangle the impact of any single determinant. A higher share of the population living in urban areas, other things equal, may be of particular importance in lowering fertility rates. In rural farming communities, many benefits accrue to a large family. Children provide farm labor—from an early age children are able to perform simple farm chores. Children can also provide, in the absence of social insurance, some guarantee of old age security for parents. These benefits of a large family are not so evident in the urban context, where they may also be outweighed by the financial costs of supporting a large family.

Other factors also influence fertility rates. Cultural and religious factors can lead to higher family size than would otherwise be predicted by indicators of social and economic development and urbanization. Algeria, Libya, Iran, and Iraq, for example, have fertility rates near or over 6 despite their relatively high per-capita incomes. On the other hand, aggressive government policies to restrict families can lead to lower family sizes than predicted by other social and economic indicators. For example, fertility rates in China, a low-income country, fell dramatically from 6 in the mid-1960s to 2.4 in 1987—lower than the rate for the industrial countries 20 years ago—due largely to strong government policy.

With a given fertility rate, the number of births will be higher if a larger share of the population is in the reproductive age group. In the developing countries, young people comprise a higher share of the population. This population structure gives a much greater "population momentum" (the tendency for population growth to continue even after fertility rates have fallen to the replacement level). In the developing countries, the rising share of women of childbearing age in the population will continue to exert strong upward pressure on the population, despite the expected drop in fertility rates.

The size of the population base is the third determinant of population growth. The highest fertility rates exist in the developing countries, which already have by far the largest share (77 percent) of the global population. This means that larger numbers are being added to the world population than would be the case if the high fertility rates applied to the industrial countries, which comprise only 15 percent of the global population.

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[1] World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), pp. 164-165.

lead to comparable increases in energy consumption. In addition, several factors inherent in the development process tend to cause commercial energy use in developing countries to rise more rapidly than the gross national product.

First, most of the people in developing countries now rely primarily on traditional biomass fuels—wood, crop wastes, animal dung—for their energy needs. These fuels are often difficult and time-consuming to gather, are inefficient and awkward to use, and can cause significant environmental damage. Similarly, most people in developing countries rely primarily on human and animal muscle power for doing their work, despite its low efficiency and limited output. People who are dependent on these traditional forms of energy will turn to commercial fuels and technologies if and when they are available and affordable. Thus, the share of traditional fuels in total energy consumption falls sharply as development proceeds. In the low-income African countries, traditional fuels account for as much as 90 percent of total energy use. In the middle-income developing countries their share falls typically to under 20 percent.

Second, most developing countries are now building their commercial, industrial, and transportation infrastructures. This requires large quantities of energy-intensive materials such as steel and cement. As a result, energy use in the near- to mid-term increases faster than income.

Third, developing countries are experiencing rapid urbanization. Urbanization has profound effects on the amount and type of energy consumed.[7] As industry and the labor force become more concentrated in urban areas, transportation needs grow. Food and raw materials are hauled longer distances, and finished products are marketed over a wider area. Urban households purchase a larger share of their total needs from outside the family, compared with rural households, and commercial providers of goods and services are more likely to use modern fuels. Scarcity of space in cities encourages the substitution of modern, compact energy forms for the bulkier biomass fuels. Finally, the growing food needs of the cities encourage changes in agricultural technology, which usually involve increased use of modern fuels and energy-intensive fertilizers.

Fourth, modern manufacturing technologies and materials have significantly lowered the real cost of many consumer goods—from radios to refrigerators—compared with costs a generation ago, and global distribution systems have increased their accessibility. People in developing countries can thus purchase many consumer goods at a far earlier point in the development cycle than did people in today's industrial countries. This could increase energy use in the near- to mid-term both to produce the materials for consumer goods and—particularly for those that are intensive energy users, such as motorcycles, cars, air conditioners, and refrigerators—to operate them.

On the other hand, there are factors that may counterbalance these trends and significantly moderate the rapid increase in energy demand.

First, the high cost of developing national energy infrastructures and of purchasing energy to support growing energy demands could potentially sharply limit economic growth. This possibility is highly undesirable given current low, and in many cases declining, living standards in developing countries.

Second, the expected growth in energy use in developing countries could be reduced through efficiency improvements. Energy is now used much less efficiently in developing countries than in industrial countries. Traditional fuels and technologies are often much less efficient than modern ones: for example, the efficiency of a typical wood-fueled cooking stove is just one-fourth that of a modern gas range. Moreover, the efficiency of energy use in the modern sector in developing countries is often far lower than that commonly achieved in the industrial countries. If developing countries adopt the most efficient technologies now available, they might achieve average energy efficiencies that are higher than those in industrial countries that have a large installed base of older and less efficient infrastructure and equipment.

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[7] Donald W. Jones, "Urbanization and Energy Use in Energy Development," *Energy Journal*, vol. 10, No. 4, October 1989.

Third, continued economic development is at some point accompanied by structural changes that shift investment from energy-intensive infrastructure (roads, buildings, etc.) to consumer goods (refrigerators, cars, etc.) and finally to less material-intensive but higher value-added goods such as personal services and electronics.

Energy use in developing countries will depend on the net impact of these opposing factors. At low levels of development the first set of factors predominates, and commercial energy consumption typically rises much faster than gross domestic product (GDP). Figure 2-5 compares per-capita commercial energy consumption with per-capita GDP for selected countries, ranging from lowest to highest income.[8] As this figure suggests, within the poorest countries commercial energy consumption rises faster than per-capita GNP; in the middle-income countries they rise at about the same rate; and at the highest levels of income, the increase in total commercial energy consumption is less than the increase in per-capita GNP.

It is often argued[9] that GNP per capita, a measure of the value of economic output in relation to population size, is an inadequate and misleading indicator of standards of living and well-being.[10] An index recently developed by the United Nations Development Programme, the Human Development Index (HDI),[11] incorporates both economic and social factors. This index is based on three indicators: life expectancy at birth, adult literacy, and per-capita purchasing power.[12] The first two are sensitive to social conditions in a country and in addition reflect underlying conditions of income distribution. Average purchasing power in a country gives some indication of material standards of living. At low values, the HDI also shows a close positive association with commercial energy consumption (see figure 2-6). Higher levels of HDI, however, can be achieved with a wide range of commercial energy consumption.

Commercial energy is only part (and for the poorest countries, a very small part) of total energy consumption. If estimates of traditional fuel consumption are included with commercial fuel to represent total energy consumption, the association between per-capita energy consumption and GNP remains close, but at lower income levels the slope is less steep than in figure 2-5.[13] Adding commercial and traditional energy together to make total energy consumption does not, however, take into account the lower conversion efficiencies of traditional energy compared with commercial energy. If traditional energy consumption were expressed in com-

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[8] The relationship between GDP per capita and commercial energy consumption shown in figure 2-5 is consistent with other studies. A per-capita income elasticity for fossil fuels of about 1.5 is given for 13 industrial and developing countries in Gerald Leach et al., *Energy and Growth* (London: Butterworths, 1986), p. 25. That is, a given increase in per-capita GNP between countries (purchasing power parity) is associated with a 50 percent higher increase in consumption of fossil fuels. Another study, based on 100 countries, reports a per-capita income elasticity of 1.26 (i.e., a given increase in per-capita GNP between countries is associated with a 26 percent higher increase in commercial energy consumption). See B.W. Ang, "A Cross-Sectional Analysis of Energy Output Correlation," *Energy Economics* (London: Butterworths, 1987), table 3, p. 280. This elasticity is based on market exchange rates; comparison of purchasing power parity GNP data increases the elasticity to 1.8. These elasticities are based on cross-sectional studies (i.e., intercountry comparison at a given point in time, rather than developments in an individual country over time), which are considered to give a more accurate picture of the long-term relationship between energy consumption and economic growth.

[9] For example, see Carlos Andres Perez, *Towards a New Way to Measure Development* (Caracas, Venezuela: Office of the South Commission in Venezuela, 1989).

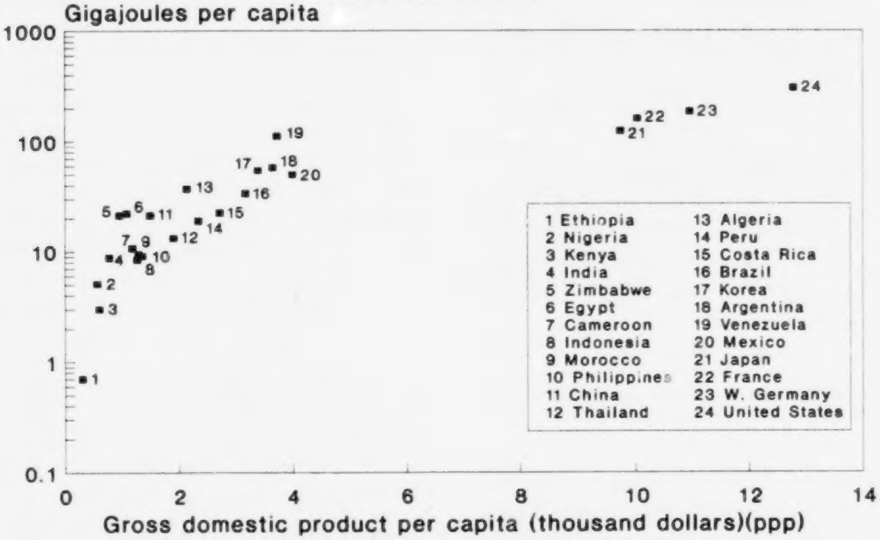
[10] GNP may be an inadequate measure of social well-being, but it nonetheless correlates strongly with many social indicators. See Partha Dasgupta, "Wellbeing and the Extent of Its Realization in Poor Countries," *The Economic Journal*, supplement (Cambridge, MA: Royal Economic Society Basil Blackwell, 1990), pp. 1-32. The argument is made here that GNP per capita also correlates closely with political and civil rights.

[11] United Nations Development Programme, *Human Development Report 1990*, op. cit., footnote 6, pp. 11-16.

[12] The values of achievement for these indicators were Japan's life expectancy at birth of 78, an adult literacy rate of 100 percent, and the average official "poverty line" income in nine industrial countries, adjusted to take into account purchasing power, of $4,861 per capita.

[13] Leach, op. cit., footnote 9, p. 25, gives per-capita income elasticities for total energy at about 1.2, lower than the 1.5 for fossil fuels alone. B.W. Ang, "A Cross Sectional Analysis of Energy Output Correlation," op. cit., footnote 9, reports income elasticities of traditional energy consumption of -0.95 (i.e., a 10 percent increase in GNP per capita is associated with a 9.5 percent *decline* in traditional energy consumption) and for total energy consumption (commercial and traditional) of 1.05.

Figure 2-5—Commercial Energy Consumption and Economic Development in Selected Countries



SOURCES: United Nations, *1986 Energy Statistics Yearbook* (New York, NY: United Nations, 1988), table 4; Robert Summers et al., "A New Set of International Comparisons of Real Product and Price Levels, Estimates for 130 Countries, 1950-1985," *Review of Income and Wealth*, Series 34, No. 1, March 1988.

mercial fuel equivalent,[14] the increase in energy consumption in relation to GNP might be somewhat greater than the increase in total energy (an energy elasticity of just over 1.0), but less than the increase in commercial energy alone (1.5 or more).

The inclusion of traditional energy, though necessary to provide a more complete picture of the relationship between economic growth, social development, and energy use, raises problems of its own. First, the measurement of traditional fuels is difficult and prone to underestimation. For example, for Indonesia, Malaysia, the Philippines, and Thailand, estimates by the United Nations Food and Agricultural Organization, the Asian Development Bank, and the World Energy Conference—three frequently quoted sources of data on traditional fuels—are found in almost all cases to be considerably lower than in other country-specific studies.[15]

Second, when considering traditional sources of energy, it is difficult to know where to draw the line. Animate forms of energy are important in most developing countries, particularly the poorest. If the biomass fed to bullocks to provide plowing and irrigation services were included, the amount of traditional energy consumed would increase substantially. Further, if the large amounts of biomass burned in preparing soil for cultivation in slash and burn agriculture were included, per-capita energy use where shifting agriculture is practiced could conceivably be as high or higher than in the industrial countries.[16]

Although GNP growth is an important determinant of energy consumption, it is not the only one. Table 2-1 shows commercial and total energy consumption relative to GNP for different levels of income. If the amount of energy consumed were tied to the level of output or development, the energy intensities of all countries would be the same. As these figures show, however, there are considerable variations in energy intensity (the ratio of energy consumption to GNP) at all levels of development. Among the industrial countries, energy intensities vary widely. And among the developing countries, energy intensities of countries with the same level of

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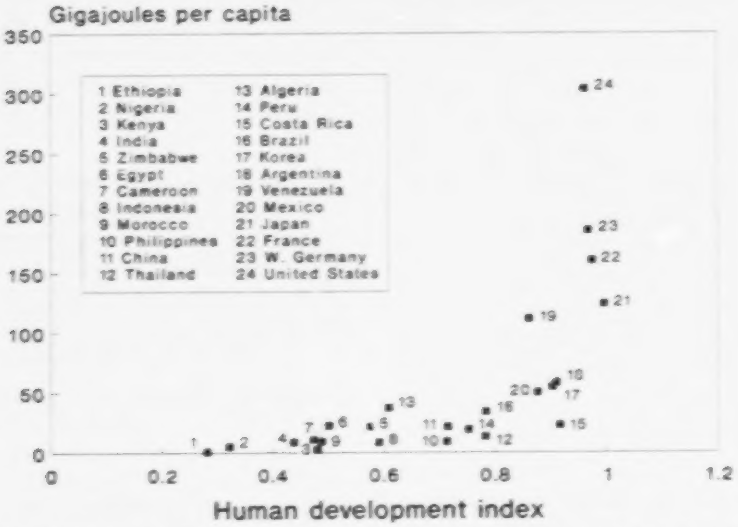
[14] B.W. Ang, "A Method for Estimating Non-commercial Energy Consumption in the Household Sector of Developing Countries," *Energy* (London: Pergamon Press, 1986), p. 423, table 8.

[15] Ang, op. cit., footnote 15, p. 423, table 8.

[16] See Kirk R. Smith, "The Biofuel Transition," *Pacific and Asian Journal of Energy*, vol. 1, No. 1, January 1987, p. 18, figure 5.

Figure 2-6—Commercial Energy Consumption and Social Development in Selected Countries



SOURCES: United Nations, *1986 Energy Statistics Yearbook* (New York, NY: United Nations, 1988), table 4; United Nations Development Programme, *Human Development Report 1990* (New York, NY: Oxford University Press, 1990), p. 79.

Table 2-1—Energy Intensities in Selected Countries

Country	Gross domestic product, 1985	Total energy consumption per GDP		Commercial energy consumption per GDP	
	$PPP*	GJ/$1,000	Index, U.S.=100	GJ/$1,000	Index, U.S.=100
Ethiopia	304	29.6	123	2.3	10
Nigeria	565	24.8	103	9.0	38
Kenya	603	29.9	124	5.0	21
India	775	15.5	64	11.4	48
Zimbabwe	954	30.4	126	22.3	94
Egypt	1,080	21.3	88	20.6	87
Cameroon	1,180	16.9	70	9.1	38
Indonesia	1,269	12.6	52	6.6	28
Morocco	1,284	7.8	32	7.3	31
Philippines	1,352	11.1	46	6.7	28
China	1,489	15.4	64	14.3	60
Thailand	1,896	12.7	53	7.0	29
Algeria	2,133	17.8	74	17.4	73
Peru	2,333	9.9	41	8.1	34
Costa Rica	2,712	16.2	67	8.3	35
Brazil	3,164	16.4	68	10.7	45
Korea	3,381	16.6	69	16.1	68
Argentina	3,640	17.0	71	15.9	67
Venezuela	3,723	29.8	124	29.9	126
Mexico	3,987	13.3	55	12.5	53
Japan	9,739	12.7	53	12.7	54
France	10,032	16.1	67	16.0	67
Germany	10,959	17.0	70	16.9	71
United States	12,787	24.1	100	23.7	100

*PPP refers to purchasing power parity.

SOURCES: United Nations, *1986 Energy Statistics Yearbook* (New York, NY: United Nations, 1988), table 4 for energy consumption data. Robert Summers et al., "A New Set of International Comparisons of Real Product and Price Levels, Estimates for 130 Countries, 1950-1985," *Review of Income and Wealth*, Series 34, No. 1, March 1988 for gross domestic product, purchasing power parity.

development (measured by GNP per capita) can vary more than fourfold.[17]

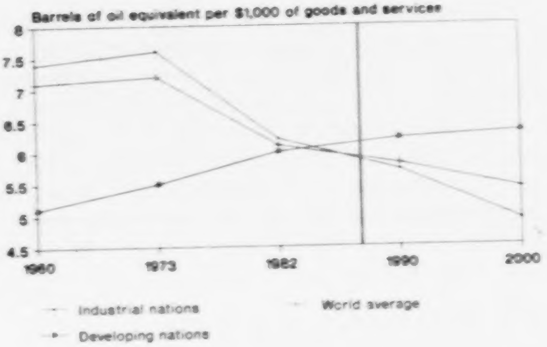
Variations in energy intensity are also evident in individual countries or groups of countries over time, as shown in figure 2-7. In the years immediately before 1973, global energy intensities rose. After 1973, there was a sharp drop in the industrial countries, in contrast to a continued rise in the developing nations, if at a lower pace. Experience within the developing countries varied considerably, again testifying to the importance of factors other than economic growth in determining energy consumption.

Differences in rates of urbanization and industrial structure account for part of the variation in energy intensities. Countries with a large share of energy-intensive industries, such as steel, paper, chemicals, and aluminum, will tend to have higher energy intensities than countries with few energy-intensive industries. Nigeria, Egypt, Algeria, and Venezuela (with large oil drilling and refinery operations) and Argentina, Korea, Zimbabwe, and China (with large metals industries, mainly iron and steel) all have relatively high energy intensities.

The impact of changes in industrial mix is also evident over time. About half of the post-1979 decline in energy intensity in China (which fell by 40 percent between the late 1970s and the late 1980s) can be ascribed to the limits on the expansion of heavy industries and to the promotion of light, and often export-oriented, manufactures (e.g., textiles, consumer electronics, processed foodstuffs, and plastics).[18] The equally dramatic decline in Korea's energy intensity is also due in large part to the changing industrial mix. Although the output of heavy industries in Korea rose sharply in these years, production of less energy-intensive industries such as machinery and transport equipment grew even more rapidly, resulting in a declining share of heavy industry in the total.

Energy intensities are also influenced by the technologies used throughout the economy. For example, the older generation of coal-burning technologies still used in developing countries are much less efficient than modern technologies. Consequently, the coal-burning countries (India and China) are more energy-intensive than countries largely reliant on oil and gas.

Figure 2-7—Energy Intensity and Economic Development, 1960-2000



SOURCE: World Bank, Industry and Energy Department, "Energy Issues in the Developing World," Energy Series Paper No. 1, February 1988.

Some of the factors that determine energy consumption (e.g., the size of the country and the location of natural resources in relation to industry and major markets) are country-specific, but others can be affected by policy decisions.

Projected Energy Consumption in Developing Countries

In the past, the three factors discussed in the preceding section—rapidly rising population, high economic growth rates to provide improved standards of living, and structural change as development gets underway—have been associated with rapid rates of increase in commercial energy consumption in developing countries. If these trends continue, increases in commercial energy consumption in developing countries could be very large. Table 2-2 illustrates some of the current projections. The synthesis of a wide range of projections shown in this table suggests that commercial energy consumption in the developing world (including here OPEC) in 2010 could be 2.5 times higher than it was in the base year, 1985, an annual rate of increase of

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[17] From the limited sample shown in table 2-1, there does not appear to be a systematic tendency for energy/GNP ratios to rise as levels of development rise; the energy/GNP ratios of the advanced developing countries are very similar to those of Europe and Japan. However, Ang, op. cit., footnote 9, using a wider sample, shows a commercial energy/GNP ratio with respect to GNP per capita at 0.80. That is, a 10 percent increase in GNP is associated with an 8 percent increase in the energy/GNP ratio.

[18] Vaclav Smil, "China's Energy: A Case Study," contractor report prepared for the Office of Technology Assessment, April 1990.

3.8 percent. China accounts for more than one-third of the projected increase.

The World Energy Conference forecasts a somewhat slower rate of growth in commercial energy consumption in the developing world, an annual average increase of 3.3 percent. By 2020, however, consumption of commercial energy in the developing world would be three times higher than in 1985, and consumption of traditional fuels about 25 percent higher (see figure 2-8). Population growth and rising standards of living each account for about half of the total increase.[19]

The Energy Sector and the Macroeconomy

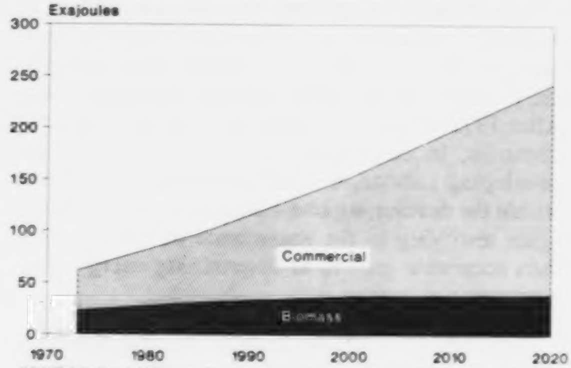
Energy is widely recognized as a key economic sector in developing countries. Reliable and affordable supplies of energy make major contributions to economic and social development; conversely, inadequate or unreliable energy supplies frustrate the development process.

Financing Energy Supplies

Most developing countries (59 out of 80) are net energy importers, relying on imports for virtually all domestic commercial energy consumption; for many countries, oil imports represent 30 percent or more of total export earnings.[20] The share of energy imports in the total export earnings of developing countries has fluctuated widely in recent years as oil prices have changed. Such wide fluctuations are highly disruptive to energy planning and economic development.

Many developing countries emphasize domestic production of energy. Investments in highly capital-intensive energy supply systems often represent a major share of the total investment budget (see table 2-3), accounting in some countries for over 40 percent of all public investment.[21] As the predominant claimant on scarce capital resources, developments in the energy sector therefore have a major impact on the amounts of investment available for other economic and social development.

Figure 2-8—Historical and Projected Energy Consumption in Developing Countries: World Energy Conference "Moderate" Projections



SOURCE: World Energy Conference, Conservation and Studies Committee, *Global Energy Perspective 2000-2020*, 14th Congress, Montreal 1989 (Paris: 1989).

The scale of future investment demands for the energy sector in developing countries is projected to be very large. The World Bank, for example, estimates that investments of $125 billion annually (twice the current level) would be needed in developing countries to provide adequate supplies of electricity.[22] According to a World Bank estimate of annual average expenditures on commercial energy supply facilities for developing countries, electricity accounts probably for one-half of the total; oil, including refineries, accounts for about 40 percent; and natural gas and coal 5 percent each. These expenditures do not include investment in small-scale renewables or energy conservation.

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[19] The Intergovernmental Panel on Climate Change has undertaken projections of energy consumption in developing countries in "Appendix Report of the Expert Group on Emissions Scenarios (Response Strategies Working Group Steering Committee, Task A)," April 1990. Several scenarios are provided, with different rates of economic growth, emission coefficients, and policies. The high economic growth (growth rates similar to the other studies quoted here), low emissions scenario forecasts a threefold increase in developing world energy consumption between 1985 and 2025, which is reasonably similar to the World Energy Conference forecast. The high growth, high emissions scenario is similar to the combined forecast results in Alan S. Manne and Leo Schrattenholzer, *International Energy Workshop: Overview of Poll Responses* (Palo Alto, CA: Stanford University, International Energy Project, July 1989).

[20] Energy imports and debt service together account for over one-third of total export earnings in middle-income countries, and almost 40 percent in lower-income countries (excluding China and India).

[21] These data cover investments in the energy sector by public entities. They may include some small amounts of investment in energy conservation, but virtually all is in energy supplies. They do not include private investment in backup equipment.

[22] World Bank, "Capital Expenditure for Electric Power in the Developing Countries in the 1990's," World Bank Industry and Energy Department Working Paper, Energy Series Paper No. 21, Washington, DC, February 1990.

Table 2-2—Commercial Energy Consumption, 1985 and Projections for 2010 (EJ=Exajoules)

	1985 (EJ)	Share of total percent	2010 (EJ)	Share of total percent	AARG,[a] 1985-2010 percent	Increase in consumption, 1985-2010 (EJ)	Share of increase percent
Developing countries	69.26	23.3	175.56	34.5	3.8	106.30	50.2
China	21.91	7.4	59.54	11.7	4.1	37.63	17.8
OPEC	11.65	3.9	28.91	5.7	2.5	17.26	8.1
Non-OPEC developing countries	35.70	12.0	87.11	17.1	3.6	51.41	24.3
OECD	155.83	52.4	215.03	42.2	1.3	59.20	27.9
United States	73.87	24.8	98.47	19.3	1.2	24.60	11.6
U.S.S.R. and Eastern Europe	72.32	24.3	118.66	23.3	2.0	46.34	21.9
Total	297.41	100.0	509.25	100.0	2.3	211.85	100.0

[a] AARG = annual average rate of growth.

SOURCE: Alan S. Manne and Leo Schrattenholzer, *International Energy Workshop: Overview of Poll Responses* (Palo Alto, CA: Stanford University, International Energy Project, July 1989).

Table 2-3—Estimated Annual Energy Investment as a Percentage of Annual Total Public Investment During the Early 1980s

Over 40 percent	30-40 percent	20-30 percent	10-20 percent	0-10 percent
Argentina Brazil Colombia Korea Mexico	Ecuador India Pakistan Philippines Turkey	Botswana China Costa Rica Liberia Nepal	Benin Egypt Ghana Jamaica Morocco Nigeria Sudan	Ethiopia

SOURCE: Mohan Munasinghe, *Electric Power Economics* (London: Butterworths, 1990), p. 5.

About one-half of total estimated energy supply investments are projected to be in foreign exchange.[23] The foreign exchange component for oil and gas is typically high (about two-thirds of the total), as much of the equipment must be imported. On the other hand, foreign exchange costs for coal development are low (about one-quarter of the total), mainly because the major coal-using countries, India and China, manufacture coal industry equipment domestically. The projected share of foreign exchange in electric power varies widely according to country. In countries with developed industrial sectors, the share may be between 5 and 10 percent, but in countries that import all their generating equipment, the share rises as high as 70 percent.[24]

Achieving these high levels of foreign resources for the energy sector investment poses immense challenges. Though most countries are likely to experience difficulties, the issues will vary from country to country. The poorest countries are highly dependent on concessional aid (which accounted for 80 percent of their total external borrowing for the energy sector in 1975-80). Their success in acquiring funds will depend on the extent of the increase in concessional flows. On the other hand, the middle-income countries depend mainly (80 percent) on export-related and private financial flows for their external financing of energy investments. The situation is particularly acute in highly indebted developing countries.

The other half of the projected increase in investment in the energy sector comes from domestic resources, with a particularly high share in electricity and coal. In many countries, however, the financial situation of the power sector has deteriorated, as increases in costs have not been matched by increased revenues.[25] The financial viability of oil refinery operations in many countries is also compromised by the structure of petroleum product prices.[26] The issue of domestic resource mobilization is of particular importance for coal, where much of the financial resources needed are local rather than foreign.

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[23] External funding for the energy sector was projected to come largely (almost three-quarters) from private sources (supplier credit and private commercial loans). Loans from multilateral agencies and bilateral aid accounted for about one-quarter.

[24] World Bank, *The Energy Transition in Developing Countries* (Washington, DC: 1983).

There are indications that the developing countries are paying increased attention to resource mobilization for the energy sector. Several countries (e.g., Peru, Ecuador, and Colombia) are currently opening more of their territories to oil exploration by foreign firms. Requirements for government participation in oil development ventures are being relaxed. Improved fiscal arrangements providing for the special characteristics of gas have been adopted in Egypt, Tunisia, Pakistan, and elsewhere with a dramatic increase in exploration specifically directed at gas.[27]

Energy Supply Reliability

Just as the presence of reliable supplies of high-quality energy can be a strong incentive to economic development, so unreliable supplies can discourage development and add substantially to the cost of usable power. Electricity supplies in many developing countries are characterized by frequent service curtailments to customers, including blackouts, brownouts, and sharp power surges. This can have two types of impacts:

- Industries and offices are unable to operate, production is lowered, and raw materials are wasted. In China, for example, it is claimed that electricity shortages and disruptions during the 1980's were responsible for idling at least 20 percent of the country's industrial capacity.[28] For the five public-sector steel plants in India, it has been estimated that at 1986-87 operating levels, irregular and restricted electricity supply resulted in increased electricity consumption of over 216 gigawatthours at a cost of $10 million, and the poor quality of the electricity resulted in additional consumption of 412 gigawatthours at a cost of $18 million.[29] More generally, lost industrial output caused by shortages of electricity in India and Pakistan is estimated to have reduced GDP by about 1.5 to 2 percent.[30] Residential consumers are also affected.
- Many consumers, both residential and industrial, are obliged to invest in a variety of equipment—voltage boosters, standby generators, storage batteries, kerosene lamps—in order to minimize the impact of disrupted supplies. Though no data are available, expenditures on these devices are certainly substantial, adding to the cost of providing usable supplies.

Such supply constraints are usually associated with electricity, but there are also shortages of other sources of energy. Supplies of household fuels in many countries (e.g., India) are notoriously intermittent. This accounts for the existence of a wide range of cooking systems in many households in order to ensure against the shortage of any one fuel. Transportation services are also subject to disruption because of unreliable fuel supplies.

Energy Pricing and Demand Management

Energy prices play a key role in energy sector development, through their impacts on the amount of energy used in an economy, the technologies adopted, and in some cases, the direction of industrial development. The effects on the energy infrastructure are long term in nature, and often difficult to reverse.

Energy pricing policy may have several objectives: efficient allocation of resources, provision of affordable supplies to consumers, reasonable returns to energy producers, substitution between fuels for national security or environmental reasons, promotion of regional development and industrial competitiveness.[31] The weights of these different objectives in the formulation of energy policy vary among countries. The importance of the regional development objective, for example, varies from country to country depending on geographical configuration, politics, and history. As in other aspects of economic and social policy, however, there are several characteristics of energy pricing that are shared by many of the developing countries:

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[25] World Bank, "Review of World Bank Lending for Electric Power," World Bank Industry and Energy Department Working Paper Energy Series, Paper No. 2, March 1988.

[26] Donald Hertzmark, "Energy Efficiency and Energy Pricing in Developing Countries," contractor report prepared for the Office of Technology Assessment, May 1990.

[27] Theodore J. Gorton, "Petroleum in the Developing World," contractor report prepared for the Office of Technology Assessment, July 1990.

[28] Vaclav Smil, "China's Energy: A Case Study," op. cit., footnote 18.

[29] Energy and Environmental Analysis, "Conserving Process Heat in Primary Industries of India and China," contractor report prepared for the Office of Technology Assessment, April 1990.

[30] Arun P. Sanghvi, "Impacts of Power Supply Inadequacy in Developing Countries," *Journal of Energy Policy* (forthcoming).

- Governments play a strong role in the commercial energy sector. In virtually all developing countries the electricity sector is government owned, and in many countries the government also owns the coal, and oil and gas sectors. Regardless of the form of ownership, the government typically regulates prices of energy products, frequently at several levels of the production and distribution chain.
- Social objectives are an important factor in formulating energy pricing policies. As a basic necessity of life, energy accounts for a substantial part of total household expenditures. Governments frequently aim to keep the typical cost of household fuels—e.g., kerosene for lighting and cooking, and in some cases electricity—low. The large number of poor in the population also makes price stability an important policy objective. Though social equity issues are a major preoccupation in the pricing of commercial fuels, prices of the most common form of energy used by the poor—wood and charcoal—are usually not regulated.
- Economic objectives, notably, the desire to encourage key strategic development sectors including transportation and agriculture, are also reflected in policies designed to promote rural electrification or to keep diesel prices low.

Policies that keep key energy product prices low can also produce adverse results. Revenues from energy sales may be inadequate to cover the costs of supplying the energy. This problem is especially acute in the electricity generating sector in developing countries. One study[32] showed that in 30 out of 37 developing countries for which data were available, electricity tariffs were too low to generate the revenues needed to cover total operating costs plus allowances for equipment replacement or expansion of the system. A survey of electric power projects financed by the World Bank over a 20-year period[33] indicates a consistent decline in key financial indicators as revenues from sales of electricity lagged behind rising costs.

Petroleum prices are rather different. At present, subsidies (defined here as prices significantly lower than those charged in international markets) are largely limited to oil-exporting (or at least oil-producing) countries. Countries that import all their supplies of petroleum products, and are therefore obliged to pay current international prices for their supplies, are generally unwilling to subsidize prices on the domestic market. In the oil-exporting countries, however, despite sharp price increases in recent years, several petroleum products—notably, kerosene and heavy fuel oil—continue to be sold at half the international price or less. Low domestic gas prices, in combination with other factors, discourage the development of gas resources and contribute to the spectacularly high share of flared gas in developing countries—47 percent of total production, compared with 4 percent in the OECD countries.[34]

In both India and China, which together account for 70 percent of all coal consumption in the developing world, coal prices are kept below production costs. In China, two-thirds of all coal enterprises lost money in 1984.[35] In the early 1980s the World Bank estimated Coal India's losses at $300 million on sales of $700 million.[36]

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[31] For further discussion of the scope and objectives of energy pricing, see Mohan Munasinghe, *Energy Analysis and Policy* (London: Butterworths, 1990); Lawrence J. Hill, *Energy Price Reform in Developing Countries: Issues and Options* (Oak Ridge, TN: Oak Ridge National Laboratory, August 1987), and Corazon Siddayao, *Criteria for Energy Pricing Policy* (London: Graham and Trotman, 1985).

[32] Lawrence J. Hill, op. cit., footnote 31, pp. 2-10 and 2-20, table 2-3.

[33] World Bank, "Review of World Bank Lending for Electric Power," Industry and Energy Department Working Paper, Energy Series paper No. 2, March 1988.

[34] Mark Kosmo, *Money to Burn? The High Cost of Energy Subsidies* (Washington, DC: World Resources Institute, 1987), p. 14. Based on International Energy Agency data.

[35] Lawrence J. Hill, op. cit., footnote 31.

[36] Mark Kosmo, op. cit., footmote 34, p. 16.

In some cases, the costs of energy supplies are also higher than necessary. Factors such as excessive staffing and poor management in the electricity sector increase costs, and there are similar inefficiencies in the oil supply sector. Insofar as the population is aware of these problems, they may be reluctant to agree to price increases that would in effect subsidize the inefficiencies of the supply system. Improved efficiencies on the supply side might make increases in prices and tariffs more palatable and also help to minimize the total cost to consumers.

In addition to the general level of energy prices, the structure of energy prices is of concern in both the electricity and petroleum product markets. Major differences in the prices charged for similar services—as in the case of electricity—or for petroleum products that can be substituted for each other—have given rise to distortions in product demand. The subsidization of some fuels (kerosene and diesel fuels) for general economic and social reasons, combined with high taxes on others (gasoline), leads to shortages of the subsidized fuels, surpluses of the highly taxed fuels, and capital investment decisions made on the basis of energy costs that do not reflect the cost of providing that energy.

In Thailand in the early 1980s, for example, price differences between gasoline, diesel, kerosene, and liquid petroleum gas (LPG) led to shortages and black markets in kerosene and LPG; the diversion of half of the total kerosene supply to the transport sector to adulterate diesel fuel; dieselization of many older vehicles by retrofitting a spark ignition engine to use diesel fuel; widespread theft of diesel fuel; and surpluses of gasoline as all vehicles used commercially changed over to diesel.[37] Similar developments in other countries have contributed to serious refinery imbalances. In recent years, Thailand has moved to reform its petroleum product pricing system, but wide price differentials persist in other countries, including Indonesia and India.

Energy pricing decisions are often motivated by the need to keep energy affordable for large populations of poor households. However, the practical implementation of such policy is difficult. It is often difficult to "target" disadvantaged groups. Energy consumption surveys indicate that the use of commercial fuels is concentrated among middle and upper income households, rather than the poor who rely mainly on wood and charcoal. Moreover, if subsidy programs expand in scale, they can lead to outcomes that penalize the very people they are designed to help. Thus, the deteriorating revenue situation of electricity systems, attributable in some measure to subsidized tariffs, leads to declining quality and availability of power supplies, which can cause factories and workshops to stop operations, thus increasing unemployment.

Though important, pricing is just one mechanism for influencing energy demand. Others include measures to inform consumers of cost-effective opportunities to save energy, the imposition of technical efficiency standards, and sponsorship of energy-efficient technologies.

Developing countries, frequently aided by donor countries and organizations, have made some progress in demand management and conservation. For example, the Association of South-East Asian Nations (ASEAN) countries (see box 2-B) have been particularly active in conservation in both industries and buildings. In addition, China has established energy conservation technical centers, which have contributed to the sharp decline in China's energy intensity. In Brazil, energy-saving protocols have been established with major industries. Korea has conducted major audits of large companies. Traffic management schemes, designed mainly to alleviate congestion, but with an energy-saving bonus, have been introduced in Brazil, Singapore, Thailand, and Venezuela. New, more energy-efficient automobile technologies have been introduced in India. And several improved wood-burning stoves have been introduced, at least one of which appears to have enjoyed considerable success.[38] On the institutional side, movements toward deregulation of economic activity, as in China in the 1980s, have improved the competitive environment under which energy decisions are taken and thus have contributed to improved energy efficiency.

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[37] Donald Hertzmark, "Energy Efficiency and Energy Pricing in Developing Countries," op. cit., footnote 26.

[38] Samuel Baldwin, Howard Geller, Gautan Dutt, and N.H. Ravindramath, "Improved Woodburning Cookstoves: Signs of Success," *AMBIO*, vol. 14, No. 4-5, 1985, pp. 280-287.

Box 2-B—Energy Conservation Initiatives in ASEAN Countries

In Southeast Asia, many governments are adopting and implementing laws to encourage energy conservation in buildings and industry. Design standards have been enacted, or are being considered, in most ASEAN countries.

In Malaysia, the Ministry of Energy, Telecommunications, and Posts has embarked on development of energy standards for new buildings, with the goal of reducing overall usage by 10 percent by 1991 (5 to 15 percent for lighting, 5 to 10 percent for air-conditioning, and 15 to 20 percent relating to heat gain through building envelopes). These standards were widely circulated for review, and were expected to be implemented during 1989. Some energy audits have been commissioned.[1]

In the Philippines, major energy consumers are required by law to have energy management programs, and large customers must report their consumption to the Office of Energy Affairs (OEA) quarterly. The OEA offers a wide range of conservation services, including an energy management training program, energy conservation briefings, industry-specific publications, assistance to the Energy Management Association of the Philippines (a private-sector group), consulting and audits, efficiency testing, and industrial efficiency monitoring. The Omnibus Energy Conservation Law mandates the development of standards for energy use in commercial buildings, for building construction materials, and for designs of commercial and industrial buildings prior to the issuance of permits for building or for adding equipment such as air-conditioning units.

Singapore encourages conservation through educational programs. Indirect controls imposed by the government's Building Control Department standardize various design features, such as overhangs and reduced window area to decrease demands for air conditioning.

In Thailand, the government's Sixth National Economic and Social Development Plan (1987-91) specified targets for increased efficiency in transportation, industry, and households. Tax reductions and low-interest loans for energy conservation equipment are available.

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[1] The 1986 standards instituted in Malaysia are as follows: 1) Buildings whose connected electric service is over 250 kVA are required to have separate meters for lighting and outlets and for air conditioning systems. 2) Lighting loads are specified for interior spaces, several building interiors, and roads and grounds in the vicinity of the building. Lighting controls are specified. 3) For air conditioning, dry bulb temperatures are set at 25 degrees Celsius and relative humidity at 65 percent, plus or minus 5 percent. Automatic setback and shutoff systems are required.

Energy and The Traditional Sector

Two-thirds of the developing world's population—some 2.5 billion people—live in rural areas[39] with low standards of living based largely on low-resource farming. This type of farming is characterized by high labor requirements, low productivity per hectare and, because of the marginal subsistence, strong risk aversion. Rural populations have little access to commercial fuels and technologies and only limited connection with the modern economy. Biomass fuels satisfy the heating and cooking needs of these populations, and muscle power largely provides for their agricultural, industrial, and transportation energy needs. Although these energy sources provide crucial energy services at little or no direct financial cost, biomass fuels, muscle power, and related traditional technologies generally have low efficiencies and limited output and productivity levels (see ch. 3).

In many areas, biomass supplies are diminishing due to a host of factors, including population growth and the expansion of agricultural lands, commercial logging, and fuelwood use (see ch. 5). The poorest rural people often have limited access to even these resources and, therefore, must spend longer periods of time foraging for fuel sources—exacerbating their already difficult economic position.

Traditional villages are complex, highly interconnected systems that are carefully tuned to their environment and the harsh realities of surviving on meager resources.[40] Because the villages are largely closed systems, changes in any one part affect other elements of village life. Changes in agricultural practices, for example, change the amount and type of energy supplies available. In turn, energy sector developments, such as rural electrification, can have major impacts on agricultural practice and income distribution. Making changes in rural systems frequently proves difficult due to the large risks that changes can pose to populations living on the margin of subsistence.

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[39] World Bank, *World Development Report 1989*, op. cit., footnote 1.

[40] See, for example, M.B. Coughenour et al., "Energy Extraction and Use in a Nomadic Pastoral Ecosystem," *Science*, vol. 230, No. 4726, Nov. 8, 1985, pp. 619-625; J.S. Singh, Uma Pandey, and A.K. Tiwari, "Man and Forests: A Central Himalayan Case Study," *AMBIO*, vol. 13, No. 2, 1984, pp. 80-87; Amulya Kumar and N. Reddy, "An Indian Village Agricultural Ecosystem—Case Study of Ungra Village, Part II: Discussion," *Biomass*, vol. 1, 1981, pp. 77-88.

The following sections examine four of the major factors that affect the linkages between energy and the economic and social development of rural economies: seasonality; inequities in the distribution of and access to resources; the role of commercial biomass in the rural economy; and gender issues in labor. Mechanizing the mundane tasks of rural life, a process facilitated by the introduction of modern fuels, could greatly increase the productivity of rural peoples. To bring about improvements, however, will require paying close attention to the numerous related complications, such as seasonality, the type of task, culture-specific labor roles, children's labor, and many others.

Seasonality

The seasons affect every aspect of rural life: the availability of food, fuel, and employment; the incidence of disease; and even the rates of fertility and mortality.[41] Labor requirements for planting are seasonally peaked to take advantage of limited rainfall and other favorable growing conditions. When rains begin, soil bacteria multiply rapidly and break down the dead plant matter in the soil left by the dry season; this process releases a large amount of organic nitrogen in the soil. Crops planted quickly after the rainfall can take advantage of this nitrogen, but a short delay leaves weeds as the main beneficiaries.[42] Labor requirements to harvest crops are similarly peaked (see figure 2-9). Thus, while there may be a large labor surplus during most of the year, labor shortages occur during the critical planting and harvesting seasons. Studies of African agriculture indicate that labor is "the major scarce resource in food production."[43]

Modern equipment could reduce the high labor demands during planting and harvesting. Even when the necessary commercial fuels are available, however, modern agricultural equipment is often prohibitively costly to purchase or rent due to the very short period in which it can be profitably used.[44] Relatively low-cost traditional technologies face similar cost barriers. For example, the average animal-drawn cart in Ungra, India, is used at just 6 percent of its annual capacity.[45]

Draft animal technologies can ease critical seasonal labor shortages to some extent. Draft animals, however, can only be used productively for little more than the short growing season, yet these animals require food year round. Limited uses for draft animals, coupled with their high food requirements, reduce the average draft animal efficiencies to just a few percent. Because of the limited supplies of fodder available, farmers often semi-starve draft animals in order to save fodder for when the animals need their strength to plow the dry-baked ground or for other purposes.[46] A shortage of draft animals may limit crops to just one per year—even in areas with potential for double cropping.[47]

Although agriculture demands very high levels of labor during the peak seasons, during the remainder of the year, rural areas experience serious under-

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[41] Robert Chambers, Richard Longhurst, and Arnold Pacey (eds.), *Seasonal Dimensions to Rural Poverty* (London: Frances Pinter Publishers, Ltd., and Tottawa, NJ: Allanheld, Osmun & Co., 1981); Robert Chambers, "Rural Poverty Unperceived: Problems and Remedies," *World Development*, vol. 9, 1981, pp. 1-19.

[42] Robert Chambers, Richard Longhurst, and Arnold Pacey (eds.), *Seasonal Dimensions to Rural Poverty*, op. cit., footnote 41, pp. 10-11.

[43] Jeanne Koopman Henn, "Feeding the Cities and Feeding the Peasants: What Role for Africa's Women Farmers?" *World Development*, vol. 11, No. 12, 1983, pp. 1043-1055.

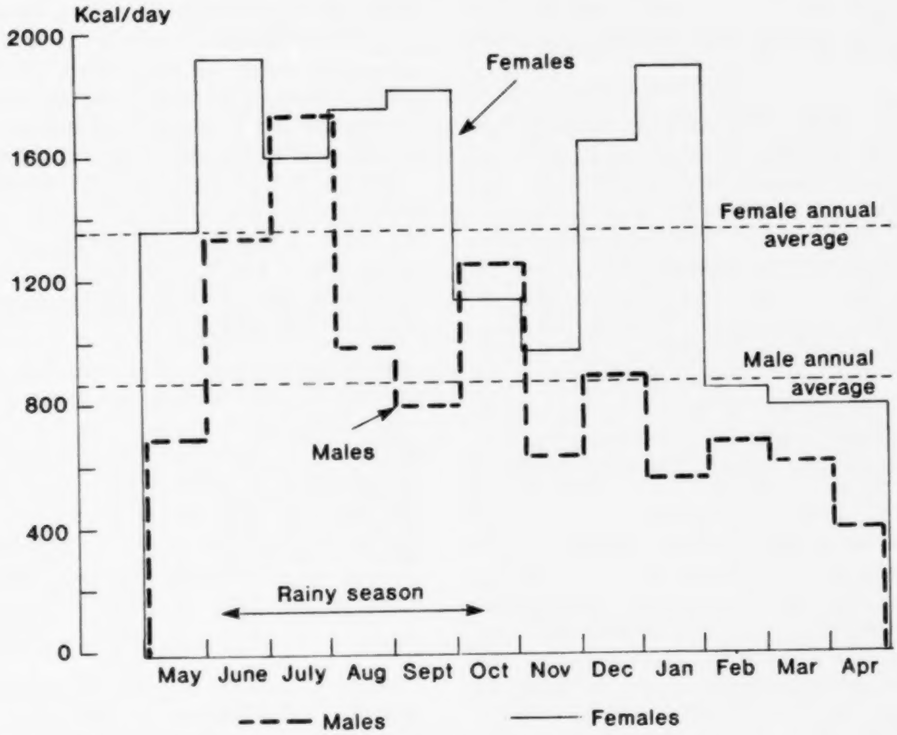
[44] Prabhu Pingali, Yves Bigot, and Hans P. Binswanger, *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa* (Baltimore, MD: Johns Hopkins University Press for the World Bank, 1987).

[45] As a consequence of low utilization rates, villagers preferred lower cost wooden wheels over higher performance pneumatic tires until the depletion of timber resources caused the price of wooden wheels to rise significantly. At the same time, these price rises led to an active market in second-hand traditional carts. H.I. Somashekar, N.H. Ravindranath, and Amulya Kumar N. Reddy, *Studies on the Ungra Village Agricultural Ecosystem, Part III: Animal Drawn Carts and Transport* (Bangalore, India: ASTRA, no date).

[46] H.I. Somashekar, N.H. Ravindranath, and Amulya Kumar N. Reddy, *Studies on the Ungra Village Agricultural Ecosystem Part III: Animal Drawn Carts and Transport*, op. cit., footnote 45; Jane Bartlett and David Gibbon, *Animal Draught Technology: An Annotated Bibliography* (London: ITDG, 1984); Peter Munzinger, *Animal Traction in Africa* (Eschborn, West Germany: GTZ, 1982).

[47] N.H. Ravindranath and H.N. Chanakya, "Biomass Based Energy System for a South Indian Village," *Biomass*, vol. 9, No. 3, 1986, pp. 215-233.

Figure 2-9—Seasonal Pattern of Energy Expenditure on Agricultural and Other Essential Tasks: Adult Farmers, Genieri Village



SOURCE: Margaret Haswell, *Energy for Subsistence* (London: MacMillan Press, Ltd., 1981).

employment. In turn, this seasonal unemployment in rural areas propels a large amount of both seasonal and permanent migration to urban areas.[48] In Africa and Asia, where the migrants are mostly men,[49] more of the burden for subsistence crop production is shifted to the women who stay behind. Migration to cities increases pressure on forests as well, because urban dwellers generally *purchase* their wood supplies, which are likely to be derived from cutting whole trees, rather than the gathering of twigs and branches as is more typical of rural foragers.

The seasons also affect the availability and usability of renewable energy resources. During the rainy season, wood is less easily obtained and more difficult to burn than during the drier months. In areas heavily dependent on crop residues for fuel, shortages at the end of the dry season can force the use of noxious weeds as substitutes, particularly by the very poor.[50] The use of biogas is limited by the availability of dung, which in Ungra, India, varies for adult cattle from 3.5 kg/day during the 7-month dry season to 7.4 kg/day during the wet season.[51] Correspondingly, in mountainous areas or elsewhere with large seasonal temperature variations, fuel demands can increase significantly during the winter. In a Kashmir village, for example, wood demands during the winter are four times higher than during the summer.[52]

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[48] Michael P. Todaro, *Economic Development in the Third World* (New York, NY: Longman, Inc., 1977); Gerald M. Meier, *Leading Issues in Economic Development*, 4th ed. (New York, NY: Oxford University Press, 1984); Scott M. Swinton, *Peasant Farming Practices and Off-Farm Employment in Puebla, Mexico* (Ithaca, NY: Cornell University, 1983).

[49] Michael P. Todaro, *Economic Development in the Third World*, op. cit., footnote 48, pp. 192-193. Note that in Latin America more women than men now migrate.

[50] Varun Vidyarthi, "Energy and the Poor in an Indian Village," *World Development*, vol. 12, No. 8, 1984, pp. 821-836.

[51] N.H. Ravindranath and H.N. Chanakya, "Biomass Based Energy System for a South Indian Village," op. cit., footnote 47.

Inequities in Resource Distribution and Access

In regions where biomass fuel supplies are limited—particularly those with dry climates and/or high population densities—rural people may travel long distances to collect fuel for domestic use, as much as 20 miles round trip in some areas under special conditions. More generally, when wood is scarce they rely on crop wastes, animal dung, or other materials as substitutes. Estimates of time spent in foraging range as high as 200 to 300 person-days per year per household in Nepal.[53] Foraging is also heavy work. In Burkina Faso, typical headloads weigh 27 kg (60 pounds).[54] In many regions, women and children shoulder most of the burden.

Despite these heavy burdens, villagers often prefer to invest their capital and labor in technologies for income-producing activities, such as yarn spinners, rather than in fuel-conserving stoves or tree-growing efforts.[55] Reasons for this investment preference include lack of cash income; the ability to minimize wood use or to switch to alternative fuels when wood becomes scarce;[56] conflicts over ownership of land or trees; and easy access to common lands. In addition, villagers often carry out fuelwood collection in conjunction with other tasks, such as walking to and from the fields or herding animals. In this case, collecting biomass resources may prove less burdensome than it appears.[57]

If wood is scarce, villagers use crop wastes, dung, or other less desirable fuels. To the village user, the immediate value of these fuels outweighs their potential long-term environmental costs.[58] In India, for example, a ton of cow dung applied to the fields produces an estimated increase in grain production worth $8 (U.S. dollars), but if burned eliminates the need for firewood worth $27 in the market.[59] The diversion of crop residues, previously used as soil enhancers, to fuel use may lead to a long-term loss in soil fertility unless offset by increased use of chemical fertilizers.

Local fuel shortages often have their most serious impacts on rural landless and/or marginal farmers with little access to fuel supplies. The poor may also sometimes be denied access to their traditional fuel sources when the market value of biomass rises.[60] For example, farm laborers in Haryana, India, are now sometimes paid in crop residues for fuel rather than in cash, although previously they had free access to these agricultural wastes.[61]

The Role of Women

Women shoulder the burden of most domestic tasks, including foraging for fuelwood and cooking. In many areas they also perform much of the subsistence agricultural labor. A 1928 survey of 140 Sub-Saharan ethnic groups found that women "carried a major responsibility for food farming" in 85 percent of the cases, and did all but the initial land clearing in 40 percent of the cases.[62] In contrast, the Muslim custom of Purdah, for example, tends to keep women near their homes and away from the fields in Bangladesh.[63] As women's work often does not produce any cash revenue, opportunities for introducing energy- and labor-saving technologies for women's work are limited. Improving labor productivity and energy efficiency in rural areas will thus require special attention to the role of women.

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[52] Majid Hussain, "Fuel Consumption Patterns in High Altitude Zones of Kashmir and Ladakh," *Energy Environment Monitor* (India), vol. 3, No. 2, September 1987, pp. 57-62.

[53] J.S. Singh, Uma Pandey, and A.K. Tiwari, "Man and Forests: A Central Himalayan Case Study," *AMBIO*, vol. 12, No. 2, 1984, pp. 80-87; Kedar Lal Shrestha, *Energy Strategies in Nepal and Technological Options* (Nepal: Research Center for Applied Science and Technology, Tribhuvan University, for the End-Use Oriented Global Energy Workshop, Sao Paulo, Brazil, June 1984). The World Bank Energy Sector Assessment for Nepal estimated that 16 percent of all labor went for fuelwood and animal fodder collection.

[54] E. Ernest, "Fuel Consumption Among Rural Families in Upper Volta, West Africa," paper presented at Eighth World Forestry Conference, Jakarta, Indonesia, 1978.

[55] Varun Vidyarthi, "Energy and the Poor in an Indian Village," op. cit., footnote 50.

[56] Phil O'Keefe and Barry Munslow, "Resolving the Irresolvable: The Fuelwood Problem in Eastern and Southern Africa," paper presented at the ESMAP Eastern and Southern Africa Household Energy Planning Seminar, Harare, Zimbabwe, Feb. 1-5, 1988.

[57] Irene Tinker, "The Real Rural Energy Crisis: Women's Time," *Energy Journal*, vol. 8, 1987, pp. 125-146.

[58] Geoffrey Barnard and Lars Kristoferson, *Agricultural Residues as Fuel in the Third World* (Washington, DC, and London: Earthscan and International Institute for Environment and Development, Energy Information Program, Technical Report No. 4, 1985).

[59] G.C. Aggarwal and N.T. Singh, "Energy and Economic Returns From Cattle Dung as Manure and Fuel," *Energy*, vol. 9, No. 1, 1984, pp. 87-90; see also G.C. Aggarwal, "Judicious Use of Dung in the Third World," *Energy*, vol. 14, No. 6, 1989, pp. 349-352; Eric Eckholm et al., *Fuelwood: The Energy Crisis That Won't Go Away* (London: Earthscan, 1984), p. 105; Ken Newcombe, World Bank, Energy Department, "An Economic Justification for Rural Afforestation: The Case of Ethiopia," 1984.

[60] Varun Vidyarthi, "Energy and the Poor in an Indian Village," op. cit., footnote 50.

[61] Centre for Science and Environment, *The State of India's Environment 1984-85: The Second Citizen's Report* (New Delhi: 1985).

The careless introduction of labor-saving technologies could increase the burden on women. For example, the introduction of animal or mechanical traction for land preparation and planting increases the area that men can cultivate, but does nothing to assist women in weeding, harvesting, post-harvest food preparation, storage, and other tasks.[64]

The migration of men to look for urban work leaves women to fulfill traditional male roles as well as their own. In Uttar Pradesh, India, the male:female ratio in villages is 1:1.4 for the working age group of 15 to 50 years.[65] In Kenya, a quarter of rural households are headed by women—in Botswana, 40 percent.[66] Yet the remittances of the migrants can make an important contribution to rural household finances.

Children, too, play an important role in rural labor, freeing adults to perform more difficult tasks.[67] In Bangladesh, for example, children begin performing certain tasks as early as age 4. By age 12, boys become net producers—producing more than they consume—and are nearly as efficient in wage work as men. By age 15, boys have produced more than their cumulative consumption from birth, and by 22 they have compensated for their own and one sibling's cumulative consumption.[68] The major role of children in farming helps explain high fertility rates in rural areas.

The Role of Commercial Biomass in the Rural Economy

While much biomass is used locally, rural areas are also the source of substantial amounts of fuelwood (both firewood and charcoal) used in towns.[69] This trade pumps relatively large amounts of cash into the rural economy and provides much-needed employment to rural dwellers during non-agricultural seasons. To supply Ouagadougou, Burkina Faso, with wood during 1975, for example, required some 325,000 person-days of labor and generated over $500,000 in income directly and an additional $2.5 million in income through transport and distribution.[70] Such marketing networks can be quite extensive and complex.[71]

In many countries, people in the poorest areas, where conditions do not permit expansion of crop or animal production and natural woody vegetation is the only resource, depend heavily on sales of firewood for their income.[72] Similarly, when crops fail, charcoal production[73]—or, as in Bangladesh, the cutting of wood from farm hedgerows grown in part as an economic buffer to be sold before more valuable livestock and land[74]—provides alternatives for earning cash. In India, for example, "headloading" (individuals carrying wood to urban markets on their heads) has become an important source of income for perhaps 2 to 3 million people.[75]

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[62] Jeanne Koopman Henn, "Feeding the Cities and Feeding the Peasants: What Role for Africa's Women Farmers? " op. cit., footnote 43.

[63] Mead T. Cain, "The Economic Activities of Children in a Village in Bangladesh," *Population and Development Review*, vol. 3, No. 3, September 1977, pp. 201-227; Gloria L. Scott and Marilyn Carr, "The Impact of Technology Choice on Rural Women in Bangladesh," World Bank, Staff Working Paper No.731, Washington, DC, 1985.

[64] Peter Munzinger, *Animal Traction In Africa*, op. cit., footnote 46.

[65] J.S. Singh, Uma Pandey, and A.K. Tiwari, "Man and Forests: A Central Himalayan Case Study," op. cit., footnote 40.

[66] World Bank, *Population Growth and Policies in Sub-Saharan Africa* (Washington, DC: 1986), p. 39.

[67] Ingrid Palmer has noted: "Children's labor, especially daughters', is usually more significant than husbands' in easing a work bottleneck for women." Ingrid Palmer, "Seasonal Dimensions of Women's Roles," in Robert Chambers, Richard Longhurst, and Arnold Pacey (eds.), *Seasonal Dimensions to Rural Poverty*, op. cit., footnote 41.

[68] Mead T. Cain, "The Economic Activities of Children in a Village in Bangladesh," op. cit., footnote 63.

[69] The value of commercialized fuelwood and charcoal exceeds 10 percent of the gross domestic product in countries such as Burkina Faso, Ethiopia, and Rwanda and exceeds 5 percent in Liberia, Indonesia, Zaire, Mali, and Haiti. Philip Wardle and Massimo Palmieri, "What Does Fuelwood Really Cost?" *UNASYLVA*, vol. 33, No. 131, 1981, pp. 20-23. George F. Taylor, II, and Moustafa Soumare, "Strategies for Forestry Development in the West African Sahel: An Overview," *Rural Africana*, Nos. 23 and 24, Fall 1985 and Winter 1986.

[70] J.E.M. Arnold, "Wood Energy and Rural Communities," *Natural Resources Forum*, vol. 3, 1979, pp. 229-252.

[71] Alain Bertrand, "Marketing Networks for Forest Fuels to Supply Urban Centers in the Sahel," *Rural Africana*, Nos. 23 and 24, Fall 1985 and Winter 1986.

The response of rural peoples to fuel shortages varies widely. Some sell wood to urban markets and use the lower quality residues themselves. Others use dung for fuel rather than for fertilizer. In Malawi, to grow sufficient fuel for household use on the typical family farm would displace maize worth perhaps 30 times more; collecting "free" wood proves much easier.[76] In contrast, aerial surveys of Kenya have shown that hedgerow planting increases with population density—demonstrating that villagers respond to the reduced opportunity of collecting free wood from communal lands by growing their own.[77]

Conclusion

High rates of economic growth will be needed in developing countries to provide the rapidly growing population with improved living standards. If present trends in energy and economic growth continue into the future, a sharp increase in commercial energy consumption in developing countries will be required. Substantial increases in supplies of biomass fuels will also be needed. This prospect raises a dilemma. On the one hand, increases in energy supplies on this scale would severely strain financial, manpower, and environmental resources. But on the other, inability to supply needed energy can frustrate economic and social development.

One way to resolve this dilemma lies in distinguishing between the energy that is consumed and the services derived from it. Technological improvements and other means offer the potential of greatly improving the efficiency of energy use—providing more of the energy services needed for development while consuming less energy. The next chapter provides an introduction to the services provided by energy, and how they are currently delivered, with a view to identifying potentials for improving efficiencies.

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[72] J.E.M. Arnold, "Wood Energy and Rural Communities," op. cit., footnote 70, Centre for Science and Environment, *The State of India's Environment 1984-85: The Second Citizen's Report*, op. cit., footnote 61.

[73] D.O. Hall and P.J. de Groot, "Biomass For Fuel and Food—A Parallel Necessity," draft for *Advances in Solar Energy*, Karl W. Boer (ed.), vol. 3, Jan. 10, 1986; Rafiqul Huda Chaudhury, "The Seasonality of Prices and Wages in Bangladesh," in Robert Chambers, Richard Longhurst, and Arnold Pacey (eds.), *Seasonal Dimensions to Rural Poverty*, op. cit., footnote 41.

[74] Rick J. Van Den Beldt, "Supplying Firewood for Household Energy," in M. Nurul Islam, Richard Morse, and M. Hadi Soesastro (eds.), *Rural Energy To Meet Development Needs* (Boulder, CO: Westview Press, 1984).

[75] Centre for Science and Environment, *The State of India's Environment 1984-85: The Second Citizen's Report*, op. cit., footnote 61, p. 189.

[76] D. French, "The Economics of BioEnergy in Developing Countries," in H. Egneus et al. (eds.), *Bioenergy 84, Volume V: Bioenergy in Developing Countries* (Amsterdam: Elsevier, 1985). It is estimated that 90 percent of all rural households collect all their wood; 10 percent purchase some of their wood at $0.50/m^3$ or $0.04/GJ. Urban households buy their wood at a cost of $0.12/GJ. In contrast, plantation-derived fuelwood can cost $1.50 to $2.00/GJ. A farmer could plant trees, but the loss of 0.4 hectare of farmland reduces maize production by a total of $125 and profit by $30. In contrast, trees produced on 0.4 hectare will be worth $6 in 7 years.

[77] P.N. Bradley, N. Chavangi, and A. Van Gelder, "Development Research and Energy Planning in Kenya," *AMBIO*, vol. 14, Nos. 4-5, 1985, pp. 228-236.

Chapter 3

Energy Services in Developing Countries

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Chapter 3

Energy Services in Developing Countries

Introduction and Summary

Energy use in the world's developing countries is increasing rapidly. In 1960, developing countries consumed just 15 percent of the world's commercial fuels; by 1985, their share had increased to about 24 percent.[1] Including traditional fuels, the developing country share of world energy consumption was about 28 percent in 1986. Developing countries might consume as much commercial energy as today's industrial countries by early in the next century.[2] Factors driving this rapid increase in energy use include population growth, economic growth, and increasing urbanization (see ch. 2). Even with this rapid growth, overall per-capita energy consumption rates in developing countries in 2025 would be just one-fifth that of the United States in 1987.

The purpose of this chapter is to examine how energy is used in developing countries. As explained in chapter 1, the focus of this report is on the services energy provides rather than the amount of energy consumed. The reason for this approach is simple: energy is not used for its own sake, but rather for the services it makes possible. For example, wood might be burned to cook food, heat water, warm a house on a winter evening, heat an industrial boiler, or to provide other services.[3] Similarly, diesel and gasoline are used primarily to provide transportation services.

There may be many different means of providing a desired service, each with its own costs and benefits. Transportation, for example, might be provided by bicycles, motorcycles, cars, buses, light rail, or aircraft. The consumer chooses among these according to such criteria as cost, comfort, convenience, speed, and aesthetics. Within these consumer constraints, a more efficient car may be preferable to an increase in refinery capacity in order to reduce capital and/or operating costs or because of its environmental benefits. Thus, in addition to engineering and economics, energy analyses should also consider social, cultural, and institutional factors. Such factors are more readily included in a services framework than in a conventional energy supply analysis.

The amount of energy consumed in the main end use markets—residential and commercial, industry, and transportation—is examined first; then the major services provided by energy are examined within each end-use market. In the household sector, the services examined are cooking,[4] lighting, space conditioning, and refrigeration; in industry, process heat and motor drive; in agriculture, irrigation and traction; and, finally, transportation. These services are chosen on the basis of their current or likely future levels of energy consumption or their social and economic impacts.

Within this services framework, changes in energy use are traced from traditional rural areas to their modern urban counterparts. The progression from the traditional rural to the modern urban illuminates well the wide range of technologies now being used in the developing countries and the dynamics of how energy use can be expected to change in the future.

Energy use in traditional rural villages reflects a much different set of considerations from that of the modern urban economy. First, traditional energy use is part of a complex and interdependent biological system, rather than being based on fossil fuels. The biomass that is used for fuel is part of a system that provides food for humans, fodder for animals, construction materials, fiber for ropes, and even traditional medicines. Similarly, the bullock that pulls a plow also provides milk, meat, leather, and dung for fertilizer or fuel.

Second, people in traditional economies carefully assess their choices and make complex tradeoffs between the numerous pressures they face in day-to-day survival, at a level seldom seen in the modern economy. Gathering fuel, for example, is not free: it costs time and personal energy that must be balanced against all the other demands that one faces, particularly during the agricultural season when labor demand is at its peak. There are also complex tradeoffs involved in gaining access to fuels on common lands or on privately owned land.

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[1] Jayant Sathaye, Andre Ghirardi, and Lee Schipper, "Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends," *Annual Review of Energy*, vol. 12, 1987, p. 253.

[2] U.S. Environmental Protection Agency, "Policy Options for Stabilizing Global Climate," vol. 2, February 1989, p. VII-30. Rapidly Changing World Scenario.

[3] In some cases, particularly in the industrialized countries, wood might be burned in a fireplace simply for aesthetic reasons.

[4] Water heating is also an important residential/commercial energy service that is often similar to cooking in terms of the technologies used. It is not, however, explicitly considered here.

Third, although people in rural areas may use energy inefficiently in comparison to what is possible with modern commercial technologies, they use energy rather efficiently and wisely given the constraints on their resources, technology, and capital.[5] They have little choice in this if they are to survive on their meager resources. Rather than maximizing production, as is done in modern industrial society, traditional peoples focus on minimizing risk in the face of the vagaries of drought and other natural disasters.

The efficiency and productivity of traditional energy technologies in developing countries can be significantly improved. To do so effectively, however, will require an understanding of the complex linkages of village life. In general, village populations operate rationally within their framework;[6] change then requires that the framework be changed through the introduction of external inputs—financial, managerial, material, and technical. The lack of success of many development programs can be attributed in part to a failure to recognize the rationality of rural lifestyles and the need to address the overall framework in which villagers operate.

For the developing countries as a whole, the residential/commercial and industrial sectors constitute the largest end use energy markets, together accounting for 85 percent of the energy used by final consumers when traditional fuels are included. Transportation accounts for the remaining 15 percent. There are, however, considerable differences among developing nations.[7] The residential/commercial sector accounts for a particularly high share of energy use in African countries (mostly in the form of biomass fuels for cooking), while industry's share is quite low. Transportation accounts for an exceptionally high share of the total in Latin America, whereas its share in India and China is low. Tables 3-1, 3-2, and 3-3 provide sectoral and energy service breakdowns for the developing countries; figure 3-1 shows per-capita energy use in rural households as determined by village surveys in Africa, Asia, and Latin America. Residential cooking and industrial process heat account for almost two-thirds of all the energy used in the developing world. About 40 percent of all energy consumed in providing these services in developing countries, or well over a quarter of the total energy consumed in developing countries, is used in India and China.

Cooking is the single largest energy use in many developing countries. There is a well-established transition in cooking fuels associated with higher incomes, improved supply availability, and urbanization. In rural areas, and in poor urban households, traditional fuels (wood, crop wastes, and dung) are used in simple stoves. In more affluent households, people switch to modern stoves and clean, convenient fuels such as kerosene, Liquefied Petroleum Gases (LPG), and electricity. Because wood stoves are relatively inefficient, households that use kerosene or LPG can consume significantly less energy for cooking than those using wood and charcoal.

Lighting technologies follow a similar technological progression, from candles or light from wood fires in some rural areas, to kerosene and butane lamps, to electricity, which is a highly prized energy service. Electricity use for lighting rises rapidly with household income.

Relatively little energy is used for residential space cooling in developing countries. Space cooling is becoming significant in commercial and government buildings, however, and energy use for space cooling is likely to grow rapidly in the future.

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[5] Notable examples of studies on this topic include: N.H. Ravindranath et al., "An Indian Village Agricultural Ecosystem—Case Study of Ungra Village, Part I: Main Observations," *Biomass*, vol. 1, No. 1, September 1981, pp. 61-76; Amulya Kumar N. Reddy, "An Indian Village Agricultural Ecosystem—Case Study of Ungra Village, Part II: Discussion," *Biomass*, vol. 1, No. 1, September 1981, pp. 77-88; M.B. Coughenour et al., "Energy Extraction and Use in a Nomadic Pastoral Ecosystem," *Science*, vol. 230, No. 4726, Nov. 8, 1985, pp. 619-625.

[6] Ibid.

[7] Energy use at the village level is fairly similar in both quantity and source (biomass), and in application (cooking, subsistence agriculture) throughout the world. Energy use by the economically well off is also reasonably similar throughout the industrial countries as well as among the urban elite in developing countries. The large differences in energy use between countries are due primarily to the relative numbers of villagers and economically well off in the population; the form and quantity of energy use by those who are making the transition between these two extremes; and the development path being followed.

Table 3-1—Total Delivered Energy by Sector, in Selected Regions of the World, 1985 (Exajoules)

	Residential/commercial		Industry		Transport		Total		
Region	Commercial fuels	Traditional fuels[a]	Commercial fuels	Traditional fuels[a]	Commercial fuels	Traditional fuels[a]	Commercial fuels	Traditional fuels[a]	Total energy
Africa	1.0	4.0	2.0	0.2	1.5	—	4.4	4.1	8.5
Latin America	2.3	2.6	4.1	0.8	3.8	—	10.1	3.4	13.5
India and China	7.3	4.7	13.0	0.2	2.0	—	22.2	4.8	27.1
Other Asia	1.9	3.2	4.0	0.4	1.9	—	7.8	3.6	11.3
United States	16.8	—	16.4	—	18.6	—	51.8	—	51.8

—Not available or not applicable.

[a] These estimates of traditional fuels are lower than those generally observed in field studies. See figure 3-1, app. 3-A, and ch. 4.

[b] This is delivered energy and does not include conversion losses.

NOTES: 1 exajoule (10^{18} Joules) equals 0.9478 Quads. The residential and commercial sector also includes others (e.g., public services, etc.) that do not fit in industry or transport. Traditional fuels such as wood are included under commercial fuels for the United States. These figures do not include conversion losses (from fuel to electricity, in refineries, etc).

SOURCE: International Energy Agency (IEA), *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989); IEA, *Energy Balances of OECD Countries 1970-1985* (Paris: OECD, 1987); and IEA, *Energy Balances of Developing Countries 1971-1982* (Paris: OECD, 1984).

Table 3-2—Delivered Energy Per Capita by Sector in Selected Regions, 1985 (gigajoules) (includes traditional fuels)

Region	Residential/commercial	Industry	Transport	Total
Africa	11.8	5.2	3.5	20.5
Latin America	12.7	12.5	9.7	34.9
India and China	6.7	7.3	1.1	15.1
Other Asia	7.2	6.2	2.7	16.1
United States	69.8	68.5	77.5	215.8

NOTE: These estimates do not include conversion losses in the energy sector and underestimate the quantity of traditional fuels used compared to that observed in field studies. See app. 3-A for better estimates of traditional fuel use and for sectoral energy use including conversion losses.

SOURCE: Derived from table 3-1.

Table 3-3—Per Capita Energy Use by Service in Selected Countries (Gigajoules)

	Brazil	China	India	Kenya	Taiwan	U.S.A.
Residential	6.2	11.7	5.5	16.9	8.9	64.9
cooking	5.3	8.5	5.0	16.4	4.7	3.5
lighting	0.3	0.4	0.5	0.5	0.7	—
appliances	0.6	—	0.05	—	3.1	13.0[a]
Commercial	1.5	0.7	0.26	0.4	4.2	45.2
cooling	0.4	—	0.13	0.24	1.9	—
lighting	0.5	—	0.05	0.16	0.8	7.2
appliances	0.6	—	0.07	—	1.5	—
Industrial	19.4	13.8	4.1	4.8	39.2	94.1
process heat	17.5	10.2	2.7	—	—	55.8
motor drive	1.6	3.6	1.3	—	—	20.4
lighting	0.1	—	0.05	—	—	—
Transport	13.3	1.2	1.3	2.7	11.5	80.8
road	12.0	0.2	0.8	1.8	10.1	66.7
rail	0.2	0.7	0.4	0.2	0.1	2.0
air	0.7	—	0.1	0.7	0.7	11.3
Agriculture	2.1	1.8	0.6	0.5	2.6	2.5
Total	43.4	27.0	11.7	25.6	67.7	288.0

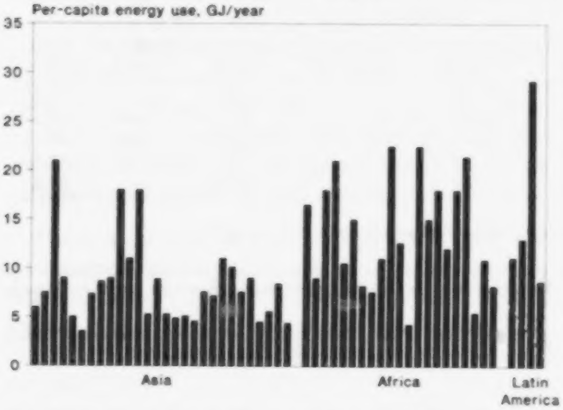
— Not available or not applicable.

[a] This is the combined total for applicances and lighting.

NOTE: These estimates include the upstream conversion losses in the energy sector, such as the loss in going from fuel to electricity or crude to refined petroleum products. This in in contrast to tables 3-1 and 3-2 where energy sector conversion losses were not included.

SOURCE: Adapted from app. 3-A, tables 1 through 6.

Figure 3-1—Per-Capita Energy Use in Village Households in Developing Countries



This figure shows per-capita use of biomass fuels as found in household energy surveys in Asia, Africa, and Latin America. The observed energy use depends on such factors as fuel availability, climate, diet, income, and other factors. The generally higher levels of energy use in Africa and Latin America reflect, in large part, the greater availability and accessibility of wood and other biomass fuels. The sporadic peaks in energy use shown in the figure are typically for villages in colder, more mountainous regions.

SOURCES: D.O. Hall, G.W. Barnard, and P.A. Moss, *Biomass for Energy in the Developing Countries* (Oxford: Pergamon Press, 1982, pp. 212; World Bank, "Bolivia: Issues and Options in the Energy Sector," UNDP/WB Energy Sector Assessment Program, Rpt. 4213-BO, April 1983; J.S. Singh, U. Pandey, and A.K. Tiwari, "Man and Forests: A Central Himalayan Case Study," *AMBIO*, vol. 12, No. 2, 1984, pp. 80-87; Issoufou Boureima and Gilles De Chambre, *Rapport sur l'Evaluation du Programme Foyers Ameliores* (Niamey, Niger: Association des Femmes du Niger and Church World Service, November 1982).

Also, electric appliances are quickly penetrating the residential sector. Many of these air conditioners and appliances, notably refrigerators, have low efficiencies. These end uses are having strong impacts on the electric power infrastructure.

Many commercial and industrial processes require process heat, ranging from the low-temperature heat provided by biomass used to dry food in cottage industries to the high-temperature processes used in the large-scale steel and cement industries. With some exceptions, the efficiencies of these processes are typically much lower than those found in industrialized countries.

Much of the population in developing countries depend for their mechanical work in both industry and agriculture on human or animal muscle, with low efficiencies and power outputs that seriously limit productivity. The efficiencies of modern diesel and electric motors are significantly lower in developing countries than in the industrialized countries as well.

As in other sectors, there is a transition in transportation technologies. Walking and use of domesticated animals are the dominant transport technologies in poorer and rural areas. The next step up is bicycles, and then the internal combustion engine. Transport services in the developing world, as in the industrial world, are based largely on highways. In the developing countries, however, freight rather than passenger traffic is the most important transport activity in terms of energy consumption.

The Residential/Commercial Sector[8]

Energy use in the residential/commercial sector of developing countries typically accounts for about 30 percent of commercial energy use and two-thirds or more of traditional fuel use (see app. 3-A). Cooking is by far the largest use of fuel in rural areas; in urban and more developed areas, lighting and appliances (refrigerators and electric fans, for example) are also large energy users. Air conditioning is likely to become important in the future in residences and is already widely used in commercial, institutional, and government buildings in developing countries.

The average energy efficiency of the most common cooking, lighting, and appliance technologies in use in developing countries today can be improved dramatically,[9] but usually at a significant additional capital cost to the consumer. Nevertheless, the advantages of these more modern technologies—convenience, comfort, effectiveness—are incentive enough for consumers to make the investment where the technologies and the necessary fuel supplies are available, affordable,[10] and reasonably reliable.

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[8] In this analysis, the residential/commercial sector includes other energy uses such as public buildings not included in the industrial and transportation sectors.

[9] This can be accomplished by changing both the mix of technology (e.g., shifting users from low-efficiency wood stoves to high-efficiency LPG stoves) and by improving the individual technologies themselves (e.g., moving toward higher efficiency refrigerators).

[10] Appropriate financial mechanisms may be needed.

Table 3-4—Principal Cooking Fuels Used by the World Population, 1976

Region	Percent of people using fuel		
	Fossil energy[a]	Fuelwood	Dung and crop waste
Africa South of Sahara	10	63	27
India	10	47	43
Rest of South Asia	12	46	42
East Asia, developing Pacific	36	41	23
Asia, centrally planned economies	22	51	27
Middle East, North Africa	53	17	30
Latin America and Caribbean	71	26	3
North America, OECD Pacific	100	0	0
Western Europe	100	0	0
Europe, centrally planned economies	100	0	0
Total	47	33	20

[a] Includes electric cooking.

SOURCE: Adapted from David Hughart, *Prospects for Traditional and Non-Conventional Energy Sources in Developing Countries*, World Bank staff working paper No. 346, 132 pp., July 1979.

Cooking[11]

The most important single energy service in many developing countries is cooking. In rural areas of developing countries, traditional fuels—wood, crop wastes, and dung—are used for cooking; in many urban areas, charcoal is also used. More than half of the world's people depend on these crude fuels for their cooking and other energy needs (see table 3-4).[12] Higher incomes and reliable fuel supplies enable people to switch to modern stoves and clean fuels such as kerosene, LPG, and electricity.

Traditional Fuels

Traditional fuels are predominant in rural areas because they can be gathered at no financial cost and used in very simple stoves—as simple as an open fire. At the national level, the use of biomass for fuel reduces expensive energy imports. These are substantial benefits.

Use of traditional fuels also exacts substantial costs. Large amounts of labor are expended to gather these fuels in rural areas, and a significant portion of household income is spent for them in poor urban areas (see ch. 2). Cooking with traditional fuels is awkward and time-consuming. Unlike modern gas or electric stoves, stoves that use traditional biomass fuels must be constantly tended to maintain an adequate flame. This demands a large share of women's time in developing countries—averaging perhaps 3 to 5 hours per day[13]—and interferes with other activities.

Cooking with traditional fuels is also usually unpleasant and unhealthy due to the large amount of noxious smoke emitted (see table 3-5). Measurements of indoor concentrations in homes in developing countries have found levels of carbon monoxide, particulates, and hydrocarbons 10 to 100 times higher than World Health Organization standards. Cooks can be exposed to as much or more carbon monoxide, formaldehyde, benzo(a)pyrene, and other toxins and carcinogens as heavy cigarette smokers.[14] Smoke from cooking stoves is therefore thought to be a significant factor in ill-health in developing

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[11] Although the discussion here focuses on household cooking, the same considerations apply to commercial and institutional settings.

[12] Heating water for bathing and cleaning and boiling water for drinking are implicitly included in the discussion here, as the technologies used are often the same for the lower and middle income groups in developing countries, and separation of energy use for these purposes is difficult.

[13] Richard Morse et al., "Organizing Current Information for Rural Energy and Development Planning," M. Nurul Islam, Richard Morse, and M. Hadi Soesastro (eds.), *Rural Energy to Meet Development Needs: Asian Village Approaches* (Boulder, CO: Westview Press, 1984), table 7, p. 498.

[14] Kirk R. Smith, *Biomass Fuels, Air Pollution, and Health: A Global Review* (New York, NY: Plenum Press, 1987)

Table 3-5—Typical Air Pollution Emissions From Various Cooking Fuels

Fuel	Efficiency (percent)	Grams per gigajoule of delivered energy[a]				
		TSP	SO_2	NO_x	HC	CO
Wood (tropical)	15	3,800	250	300	3,200	34,000
Cow dung (Hawaiian)	15	10,000	3,200	—	—	44,000
Coal (Indian)	20	280	2,200	460	2,200	27,000
Coconut husk	15	17,000	—	—	—	54,000
Natural gas	60	0.7	—	13	7	330

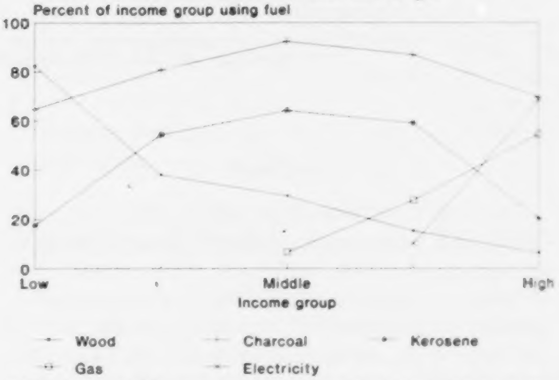
— Not available or not applicable.

[a] TSP, total suspended particulates; SO_2, sulfur dioxide; NO_x, nitrogen oxides; HC, hydrocarbons; CO, carbon monoxide.

SOURCE: Adapted from Kirk R. Smith, *Biomass Fuels, Air Pollution, and Health: A Global Review* (New York, NY: Plenum Press, 1987).

countries. The diseases implicated include severe eye irritation, respiratory diseases, and cancer.[15]

Figure 3-2—Choice of Cooking Fuel by Income for Five Medium-Sized Towns in Kenya



Many households use more than one fuel depending on the particular food cooked and the supply and cost of fuel. Note the shift in fuel choice from wood to charcoal and kerosene, and then from charcoal and kerosene to gas and electricity.

SOURCE: John Soussan, "Fuel Transitions Within Households," Discussion paper No. 35, Walter Elkan et al. (eds.), *Transitions Between Traditional and Commercial Energy in the Third World* (Guildford, Surrey, United Kingdom: Surrey Energy Economics Center, University of Surrey, January 1987).

Finally, although the expansion of agricultural and grazing lands and commercial logging are the most important causes of deforestation globally, the use of wood for fuel may also contribute to deforestation in some local areas, particularly where the population density is high and the climate is dry such as the West African Sahel (see ch. 5).

The Transition to Modern Stoves and Clean Fuels

People are generally observed to make the transition to modern, efficient stoves and clean fuels as soon as they are available and affordable (see figure 3-2).[16] These technologies are preferred for their convenience, comfort, cleanliness, ease of operation, speed, and other attributes.

There is a natural progression in efficiency, cost, and performance as consumers shift from wood stoves to charcoal, kerosene, LPG or gas, and electric stoves (see figure 3-3). Improved wood and charcoal stoves have also begun to fill a potentially important niche between traditional wood or charcoal stoves and modern kerosene or gas stoves.

Cultural factors are often cited as a barrier to the adoption of improved biomass stoves and fuels. Although cultural factors may play a role in choices of stoves or fuels, it is hardly a dominant one, as evidenced by the wide variety of stoves and fuels that have already been adopted across the full range of class, cultural, and income groups in developing countries. More typically, the reason that various stoves have not been adopted by targeted groups in

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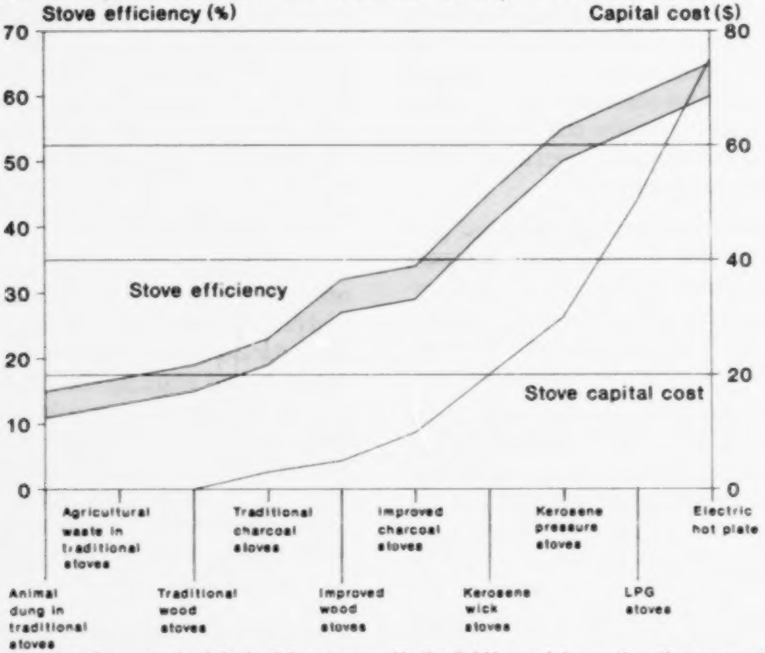
[15] Although the limited data available linking human exposure to the smoke from wood fires to lung cancer is still ambiguous (but may indicate anomalously low cancer rates), there is now evidence of excess lung cancer among cooks using certain types of coal in China. Overall, the World Health Organization now cites respiratory disease from all causes as the leading cause of mortality in developing countries. See Kirk R. Smith, "PAH and the Household Cook in Developing Countries: The Lung Cancer Anomaly," paper presented at the Symposium on Polynuclear Aromatic Hydrocarbons in the Workplace, International Chemical Congress of Pacific Basin Societies, Honolulu, HI, December 1984, to be published in M. Cooke and A.J. Dennis (eds.), *Polynuclear Aromatic Hydrocarbons: Formation, Metabolism and Measurement* (Columbus, OH: Batelle Press); J.L. Mumford et al., "Lung Cancer and Indoor Air Pollution in Xuan Wei, China," *Science*, vol. 235, Jan. 9, 1987, pp. 217-220; H.W. de Koning, K.R. Smith, and J.M. Last, "Biomass Fuel Combustion and Health," *Bulletin of the World Health Organization* (EFP/84.64).

[16] This transition is complex and not yet well understood. Factors that affect a household's shift to modern stoves and fuels include household income and fuel-producing assets (land, trees, animals, etc.); reliability of access to modern fuels; relative cost of traditional and modern fuels and stoves; level of education of the head of household; cooking habits; division of labor and control of finances within the household; and the relative performance of the stoves and fuels available.

Figure 3-3—Representative Efficiencies and Direct Capital Costs for Various Stoves



The range of performance both in the laboratory and in the field is much larger than that suggested by this figure and is affected by such factors as the size of the stove and pot, the climate (wind), the quality of the fuel used, the care with which the stove is operated, the type of cooking done, and many other factors. The type of material that the pot is made of is also a significant factor: aluminum pots are almost twice as efficient as traditional clay pots due to their better conduction of heat. Although the efficiency of improved charcoal stoves is shown as slightly higher than improved wood stoves—the case today for the simplest uninsulated metal woodstoves—the potential performance of wood stoves is higher than that for charcoal stoves.

SOURCE: Samuel F. Baldwin, *Biomass Stoves: Engineering Design, Development, and Dissemination* (Arlington, VA: VITA, 1986); and OTA estimates.

the developing countries is that they simply have not worked well.[17]

The transition to modern stoves and fuels is often sharply constrained due to their higher capital costs (figure 3-3) and uncertainty in the supply of fuel. In Colombo, Sri Lanka, for example, the cost of converting to LPG in 1983 was equivalent to 1 month's income for 70 percent of the population and 5 months' income for the poorest 20 percent.[18] Yet cooking with gas can be the lowest cost alternative when both capital and operating costs are included. In Raipur, India, the cost of cooking with LPG is less than that for wood for household discount rates of 30 percent or less; yet many households continue to use wood, presumably because effective household discount rates are higher[19] (the capital cost of gas stoves was cited as a major reason for the failure to switch from wood to LPG for cooking).

Because of the high cost of LPG cooking, charcoal and kerosene are widely used as an intermediate step in the transition from wood to gas stoves. Charcoal is very popular in some urban areas. For example, it is the fuel of choice in urban Kenya (see figure 3-2) and Senegal—which have a tradition of charcoal production and use remaining from the historical Saharan trade caravans.[20] Consumers prefer charcoal to wood because it gives off less smoke,[21] blackens pots less, requires little tending of the fire, and in some areas costs less.[22] At the national level, however, cooking with charcoal consumes far more forest resources than cooking directly with wood, due to the low energy efficiency of converting wood to charcoal—typically just 40 to 60 percent and often much lower.[23]

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[17] Samuel F. Baldwin, *Biomass Stoves: Engineering Design, Development, and Dissemination* (Arlington, VA: VITA, 1986); Sam Baldwin et al., "Improved Woodburning Cookstoves: Signs of Success," *AMBIO*, vol. 14, No. 4-5, 1985.

[18] Gerald Leach, *Household Energy in South Asia* (New York, NY: Elsevier Applied Science, 1987).

[19] J. Dunkerley et al., "Consumption of Fuelwood and Other Household Cooking Fuels in Indian Cities," *Energy Policy*, January/February 1990, pp. 92-99. "Discount rates" are a measure of the time value that households place on their available cash income.

[20] World Bank, Energy Department, "Review of Household Energy Issues in Africa," draft report, May 1987, p. 3, p. 1.6.

Kerosene is usually the next step up in the progression of cooking fuels. In many areas, kerosene prices—often subsidized or fixed by the government—form a reasonably effective cap on the price of wood and charcoal.[24] Consumers switch between these fuels according to price and availability.

LPG or natural gas is often the final step in the progression in cooking fuels. LPG is widely used by higher income groups in many urban areas, and natural gas is widely used where it is available. In Dhaka, Bangladesh, for example, over 50 percent of the urban population use natural gas; less than 10 percent use kerosene; and none use charcoal.[25] In some cases, electricity is also used for cooking by the highest income groups.

As households make the transition from wood to modern fuels, overall energy use for cooking can vary dramatically, depending on the choice of technology and the situation in which it is used. Total household energy use for cooking with kerosene (see figure 3-4) or with LPG can be significantly less[26] than that for wood or charcoal, due to the higher efficiency of kerosene and gas stoves.[27] Total household energy use for cooking with kerosene or LPG is also significantly less than for cooking with charcoal or (non-hydro) electricity, due to the low conversion efficiency of wood to charcoal and of fuel to electricity.[28]

The transition to modern stoves and fuels thus offers users many benefits—reduced time, labor, and possibly fuel use for cooking, and reduced local air pollution. Means of lowering capital and operating costs and ensuring the reliability of supply are needed if the poor are to gain access to these clean, high-efficiency technologies. At the national level, the transition to modern stoves and fuels could improve the local environment[29] and significantly reduce biomass energy consumption for cooking; to realize these benefits, however, could impose a substantial financial burden on poor nations.

A large-scale transition to LPG would require a significant investment in both capital equipment and ongoing fuel costs. Optimistically assuming that the cost of LPG systems would average $10 per capita, the investment would be roughly 3.5 percent of GNP and 20 percent of the value added in manufacturing

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[21] Charcoal stoves can, however, give off high levels of carbon monoxide—a serious health hazard in inadequately ventilated kitchens—but this does not cause as much obvious discomfort to the user as the smoke from a wood fire.

[22] Douglas F. Barnes, World Bank, Household Energy Unit, Industry and Energy Department, "Understanding Fuelwood Prices in Developing Nations," Oct. 31, 1989, table 1. Conversion to dollars per unit of energy was done using 30 MJ/kg for charcoal, and using 700 kg per cubic meter multiplied by 16 MJ/kg for wood with typical moisture contents observed in the market.

[23] The energy efficiency of the conversion process is variously given as 15 percent in Tanzania, 24 percent in Kenya with an additional loss of 5 percent of the charcoal itself during distribution, 29 percent in Senegal and Ethiopia, and over 50 percent in Brazil with brick kilns. Advanced retorts are claimed to be capable of achieving 72 percent energy efficiencies in converting wood to charcoal if there is complete recovery of all the gaseous byproducts. See E. Uhart, *Preliminary Charcoal Survey in Ethiopia*, U.N. Economic Commission for Africa, FAO Forest Industries Advisory for Africa, Doc. M75-1122, 1975, 30 pp.; M.J. and M.L. Luhanga, *Energy Demand Structures in Rural Tanzania*, Department of Electrical Engineering, University of Dar-es-Salaam, Tanzania, 1984; Phil O'Keefe, Paul Raskin, and Steve Bernow, *Energy and Development in Kenya: Opportunities and Constraints* (Sweden: Beijen Institute, 1984); G.E. Karch, *Carbonization: Final Technical Report of Forest Energy Specialist*, UNFAO, SEN/78/002, 1980.; T.S. Wood, *Report on Domestic Energy Use for Cooking* (Energy Assessment Mission, Ethiopia) (Washington, DC: World Bank, 1983), p. 33; FLORASA, *Man-Made Forests for Wood and Charcoal in Brazil* (Minas Gerais, Brazil: Florestal Acesita, S.A., Belo Horizonte, October 1983), p. 53.

[24] Douglas F. Barnes, "Understanding Fuelwood Prices in Developing Nations," op. cit., footnote 22.

[25] M.J. Prior, "Fuel Markets in Urban Bangladesh," *World Development*, vol. 14, No. 7, pp. 865-872.

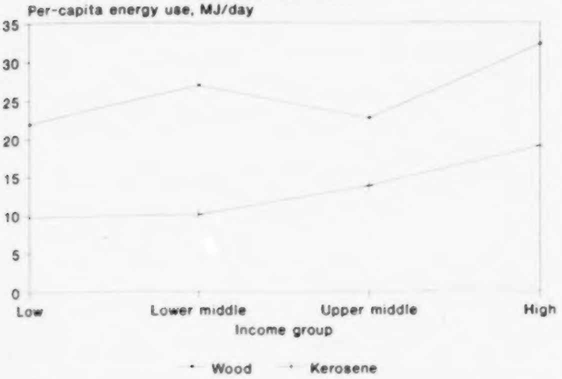
[26] Not all the potential efficiency gains of LPG may be realized by the very poor. For example, one-third to one-half of the poor in hillside shanty towns of Rio de Janeiro own just one LPG bottle. To avoid the risk of running out of gas and having no substitute, many households exchange their gas bottles before they are completely empty. See Alfredo Behrens, *Household Energy Consumption in Rio De Janeiro Shanty Towns* (Rio de Janerio, Brazil: Colegio da America Latina, 1985).

[27] In practice, however, the savings with LPG are not quite as large as would be expected from the higher efficiency and better control of these stoves. This may be due, in part, to less precise control of the stove; to taking advantage of greater useful energy; and other factors. See Kevin B. Fitzgerald, Douglas Barnes, and Gordon McGranahan, "Interfuel Substitution and Changes in the Way Households Use Energy: The Case of Cooking and Lighting Behavior in Urban Java," U.N. Working Paper on Interfuel Substitution Analysis, June 13, 1990.

[28] Other factors that affect household energy use for cooking include the size of the household, the diet, and the amount of processed or prepared foods eaten.

[29] It might, however, increase global carbon dioxide emissions.

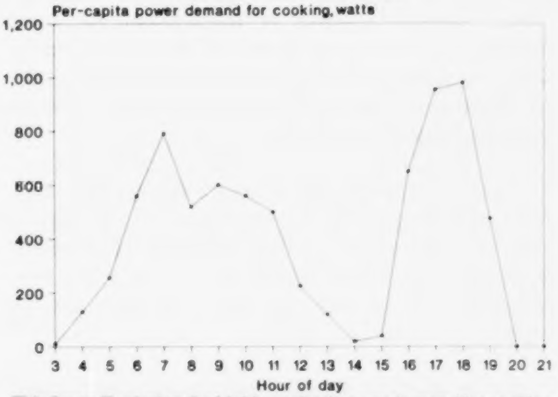
Figure 3-4—Direct Energy Use for Cooking in West Java, Indonesia



This figure compares energy use in households using only wood with that in households using only kerosene within the same income class. Households using kerosene consume roughly half as much energy as households using wood.

SOURCE: M. Hadi Soesastro, "Policy Analysis of Rural Household Energy Needs in West Java," M. Nurul Islam, Richard Morse, and M. Hadi Soesastro (eds.), *Rural Energy to Meet Development Needs: Asian Village Approaches* (Boulder, CO: Westview Press, 1984).

Figure 3-5—Daily Load Profiles for Cooking Energy, Pondicherry, India, 1980



This figure illustrates the highly peaked power demand for cooking energy as measured in a village survey.

SOURCE: C.L. Gupta, K. Usha Rao, and V.A. Vasudevaraju, "Domestic Energy Consumption in India (Pondicherry Region)," *Energy*, vol. 5, pp. 1213-1222.

for the nearly three billion people in the lowest income countries.[30] The LPG used[31] would be equivalent to one-fourth of the total commercial energy consumption today by these countries and would be a significant fraction of their export earnings.[32] Significant economic growth is needed if these costs are to be absorbed.

Costs would be even higher if electricity were used for cooking. Direct capital costs for electric burners typically approach $100 per household or more. Moreover, at the national level, the capital cost of installing generation, transmission, and distribution equipment to power electric burners is much greater, perhaps several thousand dollars per household.[33] If relatively few households are using electricity for cooking, these high capital costs are partially offset by the numerous other uses for electric power throughout the day. If a significant fraction of households switch to electricity for cooking, however, the highly peaked energy demand for cooking (see figure 3-5) will overwhelm other baseload applications, and these costs must increasingly be assigned to cooking alone.

Lighting[34]

Lighting accounts for only a small fraction of total national energy use in both developing and industrial countries. In Kenya, for example, just 1.7 percent of national energy use is for domestic lighting (app. 3-A). Lighting does, however, account for a significant fraction of total electricity use, and the electricity sector is very capital intensive (see ch. 4).

Despite its relatively low energy use, lighting merits particular attention as it plays a very important social role in domestic life and in commerce and industry, making activities possible at night or where natural lighting is inadequate. As rural incomes increase, or as people move to urban areas and gain greater access to modern fuels and electricity, lighting services and the energy used to provide them increase dramatically.

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[30] World Bank, *World Development Report, 1989* (New York, NY: Oxford University Press, 1989), tables 1 and 6.

[31] Assuming a per-capita power rate for cooking with LPG systems of 100 watts. This is comparable to that seen in the United States and about twice that seen in European countries. It is likely that people in developing countries would continue to eat less processed food, less restaurant food, and probably more grains and so would continue to use somewhat more fuel than is used in households in the industrialized countries. Energy use rates for household cooking in different countries are given in K. Krishna Prasad, "Cooking Energy," workshop on end-use focused global energy strategy, Princeton University, Princeton, NJ, Apr. 21-29, 1982.

[32] World Bank, *World Development Report, 1989*, op. cit., footnote 30, table 5. Kilograms of oil equivalent have been converted to energy at 42 MJ/kg.

[33] Assuming a peak power demand of 2 kW. A peak power demand is assumed here rather than an average power as for the LPG case above, because electric power systems cannot easily store power and must be able to meet peak demands.

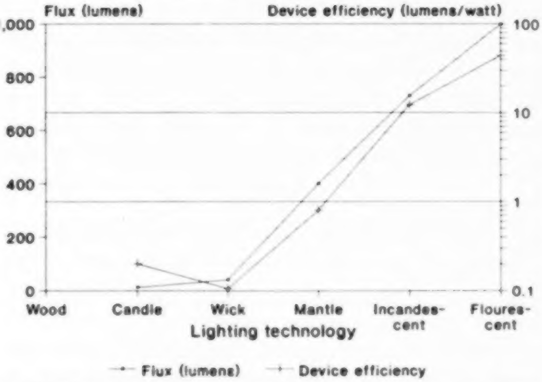
[34] Principal sources for the information in this section are Robert van der Plas and A.B. de Graaf, World Bank, "A Comparison of Lamps for Domestic Lighting in Developing Countries," energy series paper No. 6, June 1988; and Robert van der Plas, World Bank, "Domestic Lighting," Energy Sector Management and Assessments, Industry and Energy Department, working paper No. WPS 68, November 1988.

Lighting technologies follow a fairly clear technological progression in performance, efficiency, and cost (see figure 3-6). Consumers' choices of lighting technologies largely follow the same progression as household incomes increase and as electricity becomes available.

In traditional rural areas, people are often limited to the light available from wood fires, frequently obtained in conjunction with cooking. Kerosene wick lamps are usually the first step up in the progression. These may be as simple as a wick in a jar of kerosene, or as complex as a hurricane lamp with a glass chimney.[35] Glass chimney lamps generally provide more light and at a higher efficiency than open wick lamps. Glass chimney lamps also cost slightly more—a few dollars—and use somewhat more fuel. These additional costs can be a substantial barrier to their use in rural areas. For example, a survey of six villages in Bangalore, India, found that three-fourths of the households used simple open-wick lamps, and only one-fourth used lamps with glass chimneys.[36]

The light provided by wood fires, candles, or kerosene wick lamps is sufficient to find one's way, but is generally inadequate for tasks such as reading or fine work. Using two lamps doubles the cost, but does not come close to providing adequate light to work by. Thus, the poorest households tend to use just one lamp. Wealthier households may add an additional lamp or two for other rooms in the house or move up to a kerosene mantle light; however, the amount of kerosene used per household does not generally increase in proportion with income. As a result, the amount of kerosene used for lighting is similar (within a factor of two or so) across different income groups and in different regions of the world.[37]

Figure 3-6—Light Output and Efficiency of Various Lighting Technologies



Includes the candle, kerosene wick lamp, kerosene mantle lamp, 60-watt incandescent lamp, and 22-watt standard fluorescent lamp. No value is given for a wood fire, as its light output depends on size and other factors. The light output of candles and kerosene lamps are similarly highly variable; the values listed are representative. Only the efficiency of the device (plus ballast) itself is considered. System efficiencies—including refinery losses in kerosene production and generation, transmission, and distribution losses for electricity—will be considered in a later report of this OTA study.

SOURCES: Robert van der Plas, World Bank, "Domestic Lighting," Energy Sector Management and Assessments, Industry and Energy Department, working paper No. WPS 68, November 1988. Van der Plas cites the efficiency of electricity production as 30 percent, but this factor is apparently not taken into account in the incandescent light efficiency figure of 12 lm/W. See, for example, Samuel Berman, "Energy and Lighting," David Hafemeister, Henry Kelly, and Barbara Levi (eds.), *Energy Sources: Conservation and Renewables* (New York, NY: American Institute of Physics, 1985). Berman gives the output of a 100-W incandescent as 1,600 lumens and a 50-W fluorescent as 3,300 lumens. The efficiencies shown here are slightly lower corresponding to the lower, assumed wattage of the light. See also Terry McGowan, "Energy-Efficient Lighting," Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

Despite the drawbacks of kerosene wick lamps, they are a predominant technology in poor rural and urban areas. Although their light output is low, the capital and operating costs of kerosene wick lamps are also low (see figure 3-7). Further, kerosene can be purchased in small quantities as family finances

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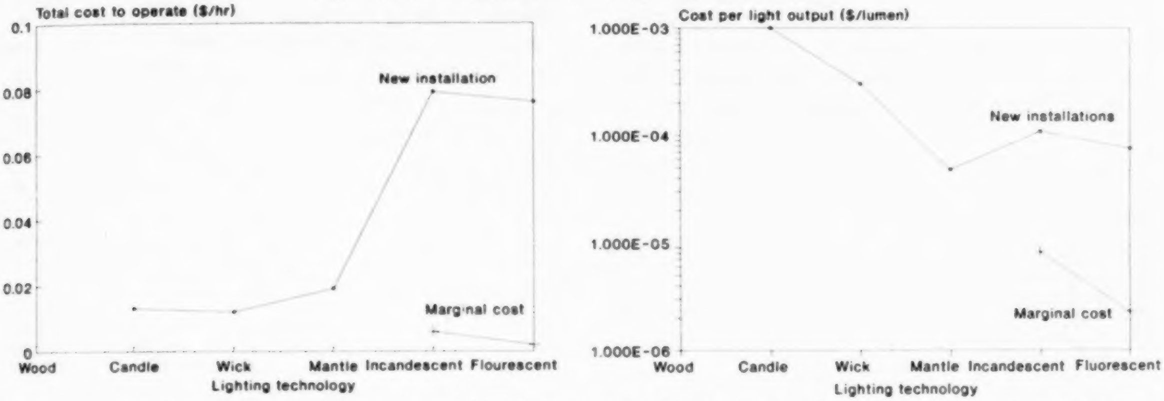
[35] The light given off by wick lamps depends on a host of factors, including size, condition of the wick (unraveled or uneven), and the amount of soot deposited on the glass chimney (if present).

[36] ASTRA, "Rural Energy Consumption Patterns: A Field Study," Bangalore, India, 1981.

[37] Gerald Leach and Marcia Gowen, World Bank, "Household Energy Handbook," technical paper, No. 67, 1987; Suliana Siwatibau, *Rural Energy In Fiji* (Ottawa, Canada: International Development Research Center, 1981); Girja Sharan (ed.), *Energy Use in Rural Gujurat* (New Delhi: Oxford and IBH Publishing Co., 1987). The Gujurat study found that one of the few variables affecting kerosene use was the number of rooms per household. Even this, however, was a relatively weak relationship.

Figure 3-7—Costs of Various Lighting Technologies



(A) Direct costs to the consumer of operating various lighting technologies per hour of service. (B) Direct costs to the consumer of various lighting technologies per unit of light output. The costs shown include only cash expenditures; they do not include labor costs for maintaining kerosene lamps, etc. The high value for electric lights shows the effect of applying all the grid connection charges to a single light, corresponding to the situation faced by the poor rural household that will initially use but one or two lights. The low value for electric lights ignores the cost of grid connection charges, corresponding to the marginal cost of adding additional lights after being connected to the grid. The assumed discount rate is 10 percent. In practice, individuals in both the developing and industrialized world tend to apply much higher discount rates when making investment decisions in energy-conserving technologies. Rates observed in the United States are typically in the range of 40 to 80 percent. Similarly, high effective discount rates have been observed in developing countries. If higher effective discount rates are applied, the higher capital costs of kerosene mantle lamps and, especially, electric grid connections will tend to present more of a barrier to investment.

SOURCES: Derived from figures 3-6 and 3-7A. See also: Harry Chernoff, "Individual Purchase Criteria for Energy-Related Durables: The Misuse of Life Cycle Cost," *Energy Journal*, vol. 4, No. 4, October 1983, pp. 81-86; David French, "The Economics of Renewable Energy Systems for Developing Countries," Washington, DC, June 1979.

permit. Kerosene wick lamps are thus well matched to the reality of rural life in developing countries, where capital and resources are sharply limited. Wood fires and/or kerosene wick lamps are the primary sources of light for more than two billion people worldwide.

Next in the progression are butane or pressurized kerosene mantle lamps. These are much like the gas lamps used for camping in the United States. Mantle lamps give substantially more light and are more efficient than wick lamps; they also cost more to purchase and operate, tend to be hot and noisy, and can cause considerable glare.

Finally, in contrast to kerosene lamps or other nonelectric lighting technologies, electric lighting is clean, relatively safe, easy to operate, efficient, and provides high-quality light. People in rural areas and small towns of developing countries place electric lighting high on their list of desired energy services. For example, a survey of 320 households in several villages and small towns of Nigeria found that 90 percent ranked electricity—primarily for lighting—as their top choice in desired energy services.[38]

Even where electric lighting is available, however, the high cost of connecting to the electric grid creates a substantial barrier for poor families that use only one or a few lightbulbs (see figure 3-7),[39] and this substantially slows penetration. A study in Gujurat, India, found that 10 years after villages had gained access to the electric grid, less than a third of the households had connected; this increased to about two-thirds after 20 years.[40] Uncertain electric supply in many developing countries—including blackouts and brownouts—also tends to discourage potential users and forces those who have connected to the grid to simultaneously maintain alternative kerosene lighting systems.

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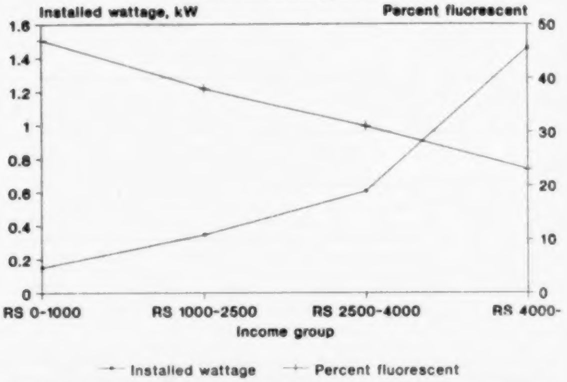
[38] Edward I. Onyebuchi, "Analysis of Rural Energy Choices in Nigeria," *Natural Resources Forum*, vol. 12, No. 2, 1988, pp. 181-186.

[39] Figure 3-7 tends to understate the barrier that grid connection costs present to people in poor rural areas. The perceived and usually the real costs to finance connection charges are often much higher in developing countries than the 10 percent discount rate assumed for this figure. Using more realistic effective discount rates of 50 percent, the cost of electric lighting—if the villager could raise the money at all—per operating hour would rise from $0.07 to $0.34, compared to $0.02 for a kerosene mantle light and $0.01 for a kerosene wick lamp. The choice of kerosene wick or mantle lamps is thus logical given the financial constraints that the poor face.

[40] Girja Sharan (ed.), *Energy Use in Rural Gujurat*, op. cit., footnote 37.

Electricity use for lighting rises rapidly with household income. For example, in South Bombay, India, rates of household electricity use during the evening varied from 93 watts for the lowest income group to 365 watts for the highest income group.[41] The choice of electric lighting technology also varies as incomes increase. Low-income households in South Bombay installed more conventional fluorescent lights—despite their higher capital cost—and operated them more intensively due to their lower operating costs. As incomes increased, households shifted away from the harsh light of conventional fluorescents to the more natural light of incandescents (see figure 3-8).[42]

Figure 3-8—Changes in Capacity and Type of Installed Electric Lighting Per Household With Income Level in South Bombay, India



Installed wattage per household and the fraction of installed wattage that is fluorescent (the remainder is incandescent) is shown versus household income in rupees. The intensity of use of this installed wattage varied with the type of lighting and the household income. The lowest income group used 80 percent of their installed capacity of fluorescents and 45 percent of their incandescents during the evening. The highest income group used just 25 percent of their installed capacity of both fluorescents and incandescents during the evening.

SOURCE: Ashok Gadgil and Bhaskar Natarajan, "Impact of Socio-Economic and Architectural Factors on Peak Electricity Demand: A Case Study of South Bombay," *Energy*, vol. 14, No. 4, 1989, pp. 229-236.

As incomes increase with economic development, households begin to buy other appliances—radios, TVs, fans, refrigerators, and air conditioners. Electricity use for lighting usually continues to increase, but it becomes only a small fraction of total residential electricity use (see figure 3-9). Electricity use for lighting in the commercial and service sectors also grows rapidly as the economy expands.

The demand for lighting has also continued to increase in the industrialized countries over the past 30 years as incomes have increased. Today, the average rate of lighting use ranges from roughly 20 to 100 million lumen-hours per capita per year (Mlmhr/cap-yr) in the industrial countries.[43] In comparison, annual household light production in South Bombay varies with household income from about 1 to 3 Mlmhr/cap-yr;[44] light production in the commercial sector might double these numbers. This is equivalent to a per-capita consumption level that is only 10 to 30 percent of the lowest levels among industrialized countries.

If lighting services equal to half the minimum level observed in the industrialized countries—10 Mlmhr/cap-yr—are to be provided in developing countries, then per-capita demand for lighting electricity will be about 500 (kWh) kilowatthours per year. This is equivalent to an evening power demand of perhaps 150 watts per capita.[45] If that level of evening demand occurred at the utility system peak load, as is typical in developing countries, then the capital cost to provide electricity for lighting would be roughly $300 per person.[46]

Space Conditioning, Refrigeration, and Other Appliances

Space Conditioning

Heating residential or commercial buildings will never be an important energy service in the majority of developing countries since most have tropical climates. Space heating will be important in some

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[41] Calculated from data in Ashok Gadgil and Bhaskar Natarajan, "Impact of Socio-Economic and Architectural Factors on Peak Electricity Demand: A Case Study of South Bombay," *Energy*, vol. 14, No. 4, 1989, pp. 229-236. The lowest income group uses 80 percent of their installed 71 watts of fluorescents and 45 percent of their installed 81 watts of incandescents; the highest income group uses 25 percent of their installed 1,460 watts of fluorescents and incandescents.

[42] This particular case contrasts with the more typical situation, as discussed for cooking, where the poor are particularly sensitive to first costs.

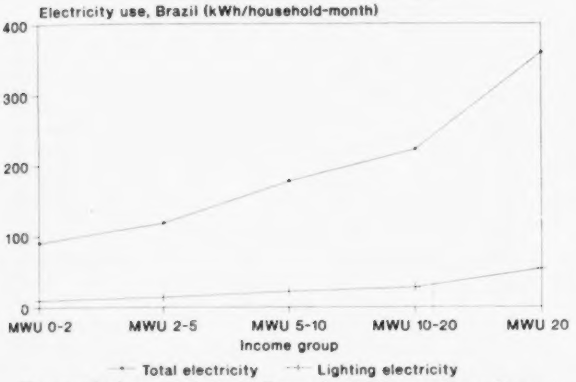
[43] Terry McGowan, "Energy-Efficient Lighting," in Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1988).

[44] Calculated from Gadgil and Natarajan, op. cit., footnote 41.

[45] This assumes that light output is equally split between incandescent and fluorescent lighting, and that the demand is in the 5 hours of the evening.

[46] Assuming an installed capital cost for the system of $2,000 per kW of generating capacity.

Figure 3-9—Household Electricity Use for Lighting v. Household Income, in Brazil



This graph shows that electricity use for lighting continues to grow with income even in a relatively properous developing country such as Brazil. Lighting electricity is, however, only a small fraction of total household electricity use in this case. MWU are minimum wage units.

SOURCE: Ashok Gadgil and Gilberto De Martino Jannuzzi, *Conservation Potential of Compact Fluorescent Lamps in India and Brazil*, Lawrence Berkeley Laboratory and Universidade Estadual de Campinas (Brazil: June 23, 1989).

areas, however, such as mountainous regions and high-latitude areas like northern China. Beijing, for example, has about the same annual average low temperature as Chicago. Nearly 20 percent of China's total annual coal consumption and 5 percent of its annual biomass consumption are used for space heating (app. 3-A).[47]

In China, residences rarely have any insulation and often have large gaps around doors and windows.[48] Indoor temperatures in these homes are controlled not by a thermostat or by comfort requirements, but by fuel supply—and fuel, though cheap, is scarce. In Kezuo county, Northeast China, for example, average indoor temperatures are at the freezing point during the winter, compared to average outdoor temperatures of −3 °C to −5 °C with lows of −25 °C.[49] Additions to coal supply, more efficient stoves, or better wall insulation would thus result mainly in comfort improvements but not in energy savings.

Similarly, although many developing countries have hot climates,[50] little energy is used at present for space cooling in developing countries. Traditional building designs somewhat moderate the extremes in temperature through natural ventilation and other techniques that make use of local materials and do not require additional energy inputs.[51] Increasing urbanization and the use of commercial building materials, however, have made these traditional practices less practical and less popular. Active space ventilation by electric fans has become popular in many areas where there is reliable electric service and costs are affordable. For example, electric fan ownership in Beijing, China, jumped from 47 percent of households in 1981 to 77 percent in 1984.[52]

Air conditioning in residences is a luxury item found only in the highest income households in developing countries (see figure 3-10).[53] In contrast, 60 percent of all homes in the United States—nearly all who need it—have air conditioners.[54] A substantial proportion of commercial, institutional, and government buildings in developing countries are air conditioned.

Air conditioning systems in developing countries are also often less efficient than those in industrialized countries. Buildings usually are poorly insulated, with large amounts of air infiltration; and air conditioners are generally less efficient than those in the west and are poorly maintained and controlled.

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[47] Vaclav Smil, "China's Energy," contractor report prepared for the Office of Technology Assessment, 1990.

[48] Robert M. Wirtshafter, "Energy-Conservation Standards for Buildings in China," *Energy*, vol. 13, No. 3, 1988, pp. 265-274; Robert M. Wirtshafter and Chang Song-ying, "Energy Conservation in Chinese Housing," *Energy Policy*, vol. 15, No. 2, pp. 158-168.

[49] World Bank, "China: County-Level Rural Energy Assessments: A Joint Study of ESMAP and Chinese Experts," Activity Completion Report No. 101/89, May 1989.

[50] All 50 of the world's hottest cities are in the developing world. The hottest is Djibouti, with an average annual high temperature of 113 °F. None of the 50 coldest cities is in the developing world. See V. Showers, *World Facts and Figures* (New York, NY: John Wiley & Sons, 1979).

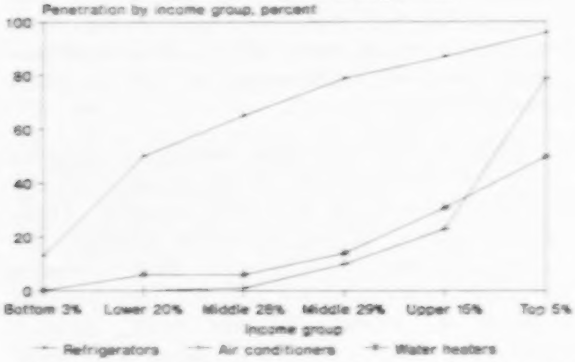
[51] Lim Jee Yuan, "Traditional Housing: A Solution to Homelessness in the Third World: The Malaysian Example," *The Ecologist*, vol. 18, No. 1, 1988, pp. 16-23; Mehdi N. Bahadori, "Passive Cooling Systems in Iranian Architecture," *Scientific American*, vol. 238, 1978, pp. 144-154; R.K. Hill, *Utilization of Solar Energy For an Improved Environment Within Housing For the Humid Tropics* (Victoria, Australia: CSIRO, 1974).

[52] J. Sathaye, A. Ghirardi, and L. Schipper, "Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends," *Annual Review of Energy*, vol. 12, 1987, pp. 253-281.

[53] Jayant Sathaye and Stephen Meyers, "Energy Use in Cities of the Developing Countries," *Annual Review of Energy*, 1985, vol. 10, pp. 109-133.

[54] Energy Information Administration, *Housing Characteristics 1984*, DOE/EIA-0314(84) (Washington, DC: U.S. Government Printing Office, October 1986), p. 5.

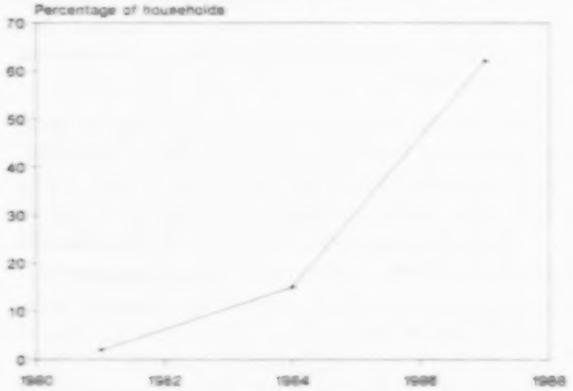
Figure 3-10—Electric Appliance Ownership in Urban Malaysia by Income Group, 1980



This figure shows the rapid penetration of refrigerators, air conditioners, and water heaters as household incomes rise. The incomes (percentage of households) are in ascending order: 150-299 Malaysian dollars per month (M$/month) (3 percent); M$ 300-599 (20 percent); M$ 600-999 (28 percent); M$ 1,000-1,999 (29 percent); M$ 2,000-4,999 (15 percent); and M$ 5,000+ (5 percent).

SOURCE: Jayant Sathaye and Stephen Meyers, "Energy Use in Cities of the Developing Countries," *Annual Review of Energy*, vol. 10, 1985, pp. 109-133.

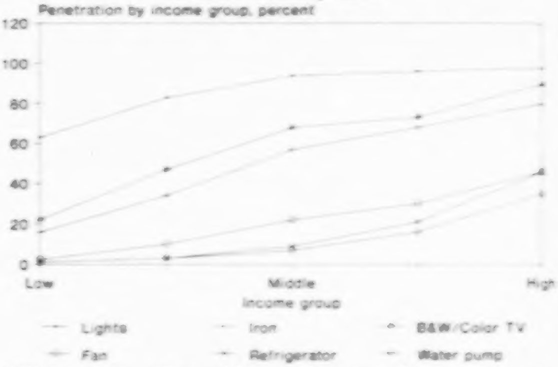
Figure 3-12—Refrigerator Ownership in Beijing, China, 1981-1987



This figure shows the rapid penetration of refrigerators into the household sector over just a 6-year period.

SOURCE: Stephen Meyers and Jayant Sathaye, "Electricity Use in the Developing Countries: Changes Since 1970," *Energy*, vol. 14, No. 8, 1989, pp. 435-441, table 6.

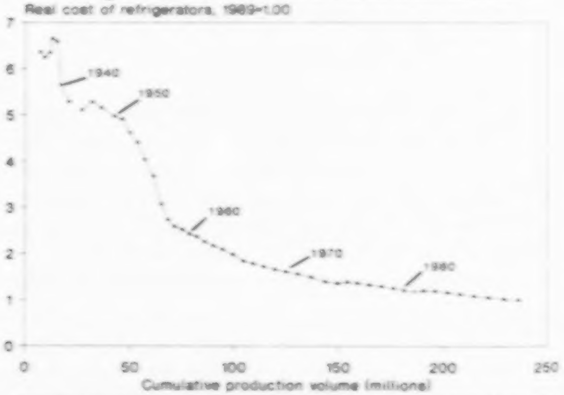
Figure 3-11—Electric Appliance Ownership in Urban Java, 1988



This figure shows the rapid penetration and relative importance within household purchasing patterns of lights, TVs, irons, fans, refrigerators, and water pumps. Income groups (share of households) in ascending order are: less than 75 (Rupees)/month (24 percent), 75-120 Rp/month (22 percent), 121-185 Rp/month (21 percent), 186-295 Rp/month (14 percent), and greater than 295 Rp/month (9 percent).

SOURCE: Lee Schipper and Stephen Meyers, "Improving Appliance Efficiency in Indonesia," *Energy Policy* forthcoming.

Figure 3-13—Reduction in the Real Cost of Refrigerators Over Time in the United States



Over the past 40 years, the real price of refrigerators has dropped by almost a factor of 5. For developing countries, such price reductions would allow households to invest in refrigerators at a much earlier point in time than was the case for the United States and other industrialized countries at a similar level of development.

SOURCES: Rick Behr, Bureau of Labor Statistics, U.S. Department of Labor, personal communication, July 9, 1990 (CPI/refrigerators); John Chirichiello, National Science Foundation SRS Computer Bulletin Board, personal communication, July 6, 1990 (GNP deflator, 1953-1989); U.S. Department of Commerce, Bureau of the Census, "Historical Statistics of the United States: Colonial Times to 1970" (Washington, DC: U.S. Government Printing Office, 1975), p. E1-12 (GNP deflator, 1935-53).

Table 3-6—Residential Nonheating Electricity Intensity in Selected Countries, 1970 and 1986 (kilowatthours per capita)

Country	1970	1986
India	7	25
Indonesia	8	33
Pakistan	10	59
Philippines	34	78
Thailand	17	110
Malaysia	37	184
Mexico	75	190
South Korea	25	248
Brazil	90	261
Argentina	210	307
Venezuela	158	422
Taiwan	163	557
Japan	—	975
West Germany	—	1,210
United States	—	3,050

— Not available or not applicable.

SOURCE: Stephen Meyers and Jayant Sathaye, "Electricity Use in the Developing Countries: Changes Since 1970," *Energy*, vol. 14, No. 8, 1989, pp. 435-441.

The potential for increased energy use for space cooling is very large. The United States now uses about 1,400 kWh of electricity per person per year for space cooling.[55] If India used this much electricity per person for space cooling, its total annual electricity generation would have to increase to more than five times present levels.[56] The hotter climate of India could increase these requirements still more.

Refrigerators and Other Appliances

Electricity-using appliances—refrigerators, televisions, washing machines, etc.—are rapidly penetrating the residential sector of developing countries. Factors contributing to this explosive growth include urbanization, increasing electrification in rural areas, economic growth, improved access to appliances, and decreasing real costs of appliances—which make them affordable to a broader segment of the population than ever before. Factors limiting appliance penetration include the lack of electric service, particularly in rural areas. In Brazil, for example, 90 percent of urban households but only 24 percent of rural households have electric service.[57]

The rapidly increasing use of household appliances in the developing countries places additional demand on electric power infrastructures that are typically already short of capacity. Further, much of the residential demand comes at peak times. A review of 13 of the largest developing countries for the period 1970-86 found that the growth rate of electricity consumption was highest in the residential sector—averaging 9.9 percent annually, compared to 8.3 percent annual growth in the industrial sector.[58] Table 3-6 shows electricity intensity for the residential sector in selected developing and industrialized countries. Even the most advanced developing countries use, on average, just a small fraction of the electricity consumed by Americans. Electricity consumption by the economically well off in developing countries, however, differs little from that found in the United States or Europe.

Lights are usually the first appliance installed when a household gets electric service. Acquisition of other appliances varies by household income and region (see figures 3-10 and 3-11). In India, fans are typically among the first appliances acquired, followed by televisions and refrigerators. In Brazil, even relatively poorer, newly electrified households often have televisions and refrigerators, as these appliances are comparatively inexpensive and are available secondhand.[59]

Refrigerator ownership is at present quite low in most developing countries. In China, for example, less than 1 percent of households have refrigerators, although refrigerator ownership has been growing rapidly in Beijing (see figure 3-12). In Brazil, 63 percent of households have refrigerators.[60] In contrast, in the United States, 99.7 percent of households have refrigerators.[61]

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[55] Gas Research Institute, Strategic Analysis and Energy Forecasting Division, *Baseline Projection Data Book* (Washington, DC: Gas Research Institute, 1988), pp. 37, 120.

[56] Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988* (New Delhi, India: 1989), p. 73.

[57] Gilberto De Martino Jannuzzi, "Residential Energy Demand in Brazil by Income Classes," *Energy Policy*, vol. 17, No. 3, p. 256.

[58] Stephen Meyers and Jayant Sathaye, "Electricity Use in the Developing Countries: Changes Since 1970," *Energy*, vol. 14, No. 8, 1989, pp. 435-441.

[59] A. Gadgil and G. De Martino Jannuzzi, *Conservation Potential of Compact Fluorescent Lamps in India and Brazil*, LBL-27210 (Berkeley, CA: Lawrence Berkeley Laboratory, July 1989), p. 5.

[60] Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report prepared for the Office of Technology Assessment, March 1990, p. 17.

[61] Energy Information Administration, *Housing Characteristics 1984*, op. cit., footnote 54, p. 13.

The refrigerators used in developing countries are typically half the size of American refrigerators, or smaller. They are also much less efficient than the best refrigerators now commercially available (the average refrigerator used in the United States is similarly much less efficient than the best available). In Indonesia, most refrigerators are assembled locally from imported components and, in general, do not take advantage of proven energy efficiency features such as rotary compressors and increased insulation.[62] The efficiency of Brazilian refrigerators is being improved—electricity consumption by the average new model was reduced by 13 percent between 1986 and 1989—but they are unable to make use of the very efficient motor-compressors (which Brazil manufactures and exports), as these units cannot tolerate the voltage fluctuations found in Brazil.[63]

Advances in materials and manufacturing techniques, coupled with a growing secondhand market, are forcing down the first cost of refrigerators and other appliances. The real cost of new refrigerators in the United States, for example, has plummeted by a factor of nearly 5 over the past 40 years (see figure 3-13). This trend should make many household appliances affordable to a much larger share of developing country populations than was the case for today's industrialized countries at a comparable level of development—a generation or more ago. As a result, energy use could increase significantly above the historical record in the near to mid-term. For example, the average new refrigerator in the United States uses about 1,000 kWh of electricity per year.[64] If every household in China had a U.S.-style refrigerator, an additional 200,000 gigawatthours (GWh) of electricity per year—or the output of about 50 full-size coal-burning power plants—would be required, at a cost for the power plants alone of about $100 billion.[65]

The Industrial Sector

The industrial sector typically consumes 40 to 60 percent of total commercial fossil energy in developing countries (see table 3-1);[66] it also makes heavy use of traditional biomass fuels—often traded in commercial markets. The primary energy services required by industry are process heat and mechanical drive. These services will be treated generically here; in a later report of this OTA study, they will be examined as specific parts of integrated industrial processes.

Firms in the industrial sector of developing countries today vary widely in size and sophistication. At one end of the spectrum are small traditional firms that use relatively energy-inefficient and low-productivity manufacturing technologies.[67] At the other end are large, modern firms, often with multinational parent companies, that have world-class manufacturing capabilities.

Manufacturing operations typically fall into three broad size categories—household or cottage, small workshops and factories, and large-scale industry. Over time, a few smaller companies tend to grow into large ones as the transport infrastructure improves and incomes rise, increasing the size of markets and providing economies of scale that turn the advantage to larger firms.[68]

In many developing countries, one-half to three-quarters of manufacturing employment is in household-scale establishments, with the remainder divided between medium and large operations. Much of the employment in the small traditional (and largely rural) household industries is seasonal labor available during the nonagriculturally active times of year. Typically one-fourth to one-third of rural

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[62] Lee Schipper, "Efficient Household Electricity Use in Indonesia," Lawrence Berkeley Laboratory, draft report, January 1989, p. 3, section on "Conservation Potential."

[63] Howard S. Geller, *Electricity Conservation in Brazil: Status Report and Analysis*, op. cit., footnote 60, p. 29.

[64] Howard S. Geller, "Residential Equipment Efficiency," contractor report prepared for the Office of Technology Assessment, May 1988. 1990 NAECA standard.

[65] Assuming: 5 people per household, 45 percent load factor, no transmission and distribution losses, and a capital cost of $2,000 per kW of installed capacity.

[66] J. Sathaye, A. Ghirardi, L. Schipper, "Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends," op. cit., footnote 52, table 5.

[67] Although they are small and often use little modern technology or methods, these manufacturing enterprises are not inefficient in some respects. High transport and marketing costs and small market size might greatly raise the cost to larger, modern firms if they should try to enter these small village markets, making them the higher cost producers.

[68] Dennis Anderson, World Bank, "Small Industry in Developing Countries: Some Issues," Staff Working Paper No. 518, 1982.

Table 3-7—Kenyan National Energy Use by Fuel, 1980 (percent of total)[a]

Energy service	Commercial fuels	Biomass fuels			
		Wood	Charcoal	Other	Total
Household	2.9	46.3	6.6	2.7	58.5
Cooking/heating	1.0	46.3	6.1	2.7	—
Lighting	1.7	—	—	—	—
Other	0.2	—	0.5	—	—
Industry	8.6	14.5	1.0	—	24.1
Large	8.6	5.3	0.3	—	—
Informal urban	—	0.1	0.6	—	—
Informal rural	—	9.1	0.1	—	—
Commerce	0.6	0.5	0.1	—	1.2
Transportation	13.7	—	—	—	13.7
Agriculture	2.5	—	—	—	2.5
Total	28.4	61.3	7.6	2.7	100.0

— Not available or not applicable.

[a] Total national energy consumption = 332 million gigajoules; per capita power consumption = 658 watts.

SOURCE: Phil O'Keefe, Paul Raskin, and Steve Bernow (eds.), *Energy and Development in Kenya: Opportunities and Constraints* (Uddevalla, Sweden: Beijer Institute and Scandinavian Institute of African Studies, 1984).

nonfarm employment is in manufacturing.[69] This is an important source of income and employment for the rural and poor urban sectors.[70]

Process Heat

Many commercial and industrial processes require heat—ranging from the low-temperature heat used to dry food by cottage industry to the high-temperature processes used by large industries to produce steel and cement. The efficiencies of these processes are typically much lower than those found in industrialized countries.

Traditional Process Heat Technologies

Biomass is used extensively in both traditional rural and more modern industry in developing countries. In Kenya, for example, large industry accounts for about 8.6 percent of national energy use in the form of commercial fuels, and 5.6 percent of total national energy consumption in the form of biomass (wood and charcoal). Informal rural and urban industries use little or no commercial fuel, but they account for about 10 percent of total national energy use in the form of biomass (see table 3-7). Rural applications include beer brewing, blacksmithing, crop drying, and pottery firing (see table 3-8).

Estimates of the use of biomass energy for industrial processes are similarly high elsewhere. Tobacco curing uses 11 percent of all fuelwood in Ilocos Norte, Philippines, and represents 17 percent of the national energy budget in Malawi.[71] In Indonesia, the brick, tile, and lime industry consumes roughly 2.5 percent of national energy use.[72] Beer brewing uses 14 percent of the total fuelwood consumed in Ouagadougou, Burkina Faso.[73] Overall, biomass fuels supply up to 40 percent of the industrial energy used in Indonesia, 28 percent in Thailand, 17 percent in Brazil, and similarly large fractions in many other countries.[74]

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[69] Dennis Anderson and Mark Leiserson, ''Rural Nonfarm Employment in Developing Countries,'' *Economic Development and Cultural Change*, vol. 28, No. 2, 1980, p. 245, table A2, cited in Donald W. Jones, *Energy Requirements for Rural Development* (Oak Ridge, TN: Oak Ridge National Laboratory, June 1988).

[70] Enyinna Chuta and S.V. Sethuraman (eds.), *Rural Small-Scale Industries and Employment in Africa and Asia* (Geneva: International Labor Office, 1984).

[71] E.L. Hyman, ''The Demand for Woodfuels by Cottage Industries in the Province of Ilocos Norte, Philippines,'' *Energy*, vol. 9, pp. 1-13, 1984; E.M. Mnzava, ''Village Industries vs. Savannah Forests,'' *UNASYLVA*, vol. 33, No. 131, 1981, pp. 24-29; E.M. Mnzava, ''Fuelwood and Charcoal in Africa,'' W. Paley, P. Chartier and D.O. Hall (eds.), *Energy from Biomass* (London: Applied Science Publishers, Ltd., 1980); M.J. Mwandosya and M.L. Luhanga, *Energy Demand Structures in Rural Tanzania* (Princeton, NJ: Center for Energy and Environmental Studies, Princeton University, and Dar-Es-Salaam, Tanzania: Department of Electrical Engineering, University of Dar-Es-Salaam, 1984).

[72] World Bank, Energy Sector Management Assistance Program, ''Indonesia, Energy Efficiency Improvement in the Brick, Tile and Lime Industries on Java,'' March 1987.

[73] Henri Chauvin, ''When an African City Runs Out of Fuel,'' *UNASYLVA*, vol. 33, No. 133, 1981, pp. 11-20.

[74] Joy Dunkerley et al., *Energy Strategies for Developing Countries* (Baltimore, MD: Johns Hopkins University Press, 1981), p. 265.

Table 3-8—Annual Consumption of Fuelwood and Charcoal in Kenya by Rural Cottage Industries, GJ/Capita

Industry	Fuelwood	Charcoal[a]
Brewing	1.07	—
Construction wood	0.50	—
Butchery	0.24	0.06
Restaurants	0.17	0.04
Baking	0.13	—
Brick firing	0.06	—
Blacksmithing	—	0.06
Crop drying	0.04	—
Tobacco curing	0.04	—
Fish curing	0.02	—
Total	2.27	0.16

— Not available or not applicable.

[a] This does not include the losses in converting wood to charcoal.

SOURCE: Phil O'Keefe, Paul Raskin, and Steve Bernow (eds.) *Energy and Development in Kenya: Opportunities and Constraints* (Uddevalla, Sweden: Beijer Institute and Scandinavian Institute of African Studies, 1984).

The efficiency with which these tasks are done can be quite low (see table 3-9). On close examination, however, the performance of traditional biomass-fueled technologies is often found to be carefully optimized in terms of efficiency, capital, and labor, given existing materials and technological constraints. An example of this is the traditional brick kiln in Sudan, which holds as many as 100,000 bricks at a time and gains economies through size and other design factors. To improve the performance of these technologies usually requires the input of modern materials and technologies, including modern means of measuring efficiencies.

Modern Large-Scale Industry

Modern large-scale industries in developing countries are modeled after their counterparts in industrialized countries, but they are often operated at significantly lower efficiencies. A few energy-intensive materials—steel, cement, chemicals (especially fertilizer), and paper—account for much of the energy used by industry (see table 3-10). The total energy used to produce these materials will increase rapidly as developing countries build their national infrastructures.

Steel—In the OECD countries, the steel industry typically consumes about one-fifth of the energy used in the industrial sector.[75] Developing countries such as China, India, and Brazil devote a similar share—18 percent, 23 percent, and 20 percent, respectively[76]—of industrial commercial energy consumption to steel production. The top 10 producers account for about 90 percent of the crude steel made in the developing world; many other developing countries produce little or no steel.

Per-capita steel consumption increases rapidly as national infrastructures are built, and then tends to saturate the market and level off at higher income levels[77] (see figure 3-14). A similar trend has been found for a wide variety of materials.[78] Simply put, there is a limit to the number of steel-intensive cars, refrigerators, washing machines, buildings, bridges, pipelines, etc., a person needs. Eventually, consumption levels tend to plateau at replacement levels. When these wants for basic materials are fulfilled, people tend to spend incremental income on higher value-added materials—such as those with a high-quality finish—or on less material-intensive but higher value-added consumer goods.

The level of per-capita steel consumption needed to provide a given service has also been reduced over time through a variety of technological improvements, including higher weight-to-strength steel alloys, more efficient motors and engines, better design, and the substitution of alternative products such as high-performance plastics. For example, the tensile strength of steel increased fourfold between 1910 and 1980.[79]

Overall steel production has been increasing by a little over 7 percent per year in the developing countries, while remaining relatively constant in the industrialized countries. At current rates, steel production by developing countries will overtake that in the industrialized countries early in the next century.

The energy efficiency of steel production in the developing countries varies widely. In some cases, it has significantly lagged that of the industrialized

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[75] Maurice Y. Meunier and Oscar de Bruyn Kops, "Energy Efficiency in the Steel Industry With Emphasis on Developing Countries," World Bank technical paper, No. 22, 1984.

[76] Ibid.

[77] Per-capita steel consumption increases approximately linearly with per-capita income up to several thousand dollars.

[78] Robert H. Williams, Eric D. Larson, and Marc H. Ross, "Materials, Affluence, and Industrial Energy Use," *Annual Review of Energy*, vol. 12, 1987, pp. 99-144.

[79] Economic Commission for Europe, *Evolution of the Specific Consumption of Steel* (New York, NY: United Nations, 1984).

Table-3-9—Efficiency of Fuel Use In Traditional (Developing Countries) and Modern (Industrial Countries) Commercial and Industrial Operations

Activity	Location	Estimated efficiency of traditional technology (percent)	Estimated efficiency of modern technology in U.S. (percent)
Cooking	West Africa	15-19	50-60
Beer brewing	Burkina Faso	15-17	79
	Burkina Faso	0.3-0.7	0.6
Tobacco drying	Tanzania	0.5	—
Tea drying	Tanzania	2.9	—
Baking	Sudan	12 -19	43
	India	16	—
	Guatemala	3	—
Fish smoking	Tanzania	2-3	—
Brick firing	Sudan	8 -16	6-11
	India	6.4	—
	Uganda	5 -10	—
Foundry work	Indonesia	3	40

NOTE: — Not applicable or not available.

SOURCE: For complete list of sources, see app. 3-B.

Table 3-10—Energy Consumption by Chinese Industry, 1980

Sector	Final energy use	
	Exajoules	Percent
Basic metals (iron and steel)	2.38	25.7
Chemicals (fertilizer)	2.23	24.1
Building materials (cement, brick, tile)	1.44	15.6
Machine building	0.82	8.8
Textiles	0.64	6.9
Food, beverages, tobacco	0.38	4.1
Pulp and paper	0.25	2.7
Other	1.12	12.1
Total	9.26	100.0

SOURCE: World Bank, *China: The Energy Sector* (Washington, DC: 1985).

countries. Integrated steel plants in India and China currently use, on average, 45 to 53 gigajoules (GJ) per ton of crude steel produced; integrated steel plants in the United States and Japan use half as much energy.[80] Some developing countries have made significant strides to reduce energy use in steel production. The Brazilians, for example, cut energy consumption from 34 GJ to 27 GJ per ton of crude steel between 1975 and 1979,[81] and the South Korean steel industry is among the most efficient in the world.

Cement—The cement industry typically consumes 2 to 6 percent, and sometimes more, of the commercial energy used in developing countries. The use of cement is expected to increase rapidly as national infrastructures of roads, bridges, buildings, etc., are built. In general, per-capita consumption of cement increases approximately linearly with income up to several thousand dollars, and then saturates and levels off at higher incomes (see figure 3-15). Despite the energy intensity of cement production, it is one of the least energy-intensive construction materials when in its final form of concrete/aggregate (see tables 3-11 and 3-12).

The value of cement is quite low compared to its weight. Because of this and because the raw materials for cement—limestone, various clay minerals, and silica sand—are widely available, cement is usually produced relatively near its point of use. In the United States, the maximum range for truck shipments of cement is about 300 km. In developing countries, where the transport infrastructure is less well developed, economical transport distances are often less. In China, for example, 150 to 200 km is the typical limit of transport; if transport over longer distance is needed, the construction of a new cement plant in the local area will be considered.[82] Thus, as a result of inadequate transport infrastructures, cement plants are often small and relatively inefficient.

The energy required to produce cement varies widely with the type of production process, quality

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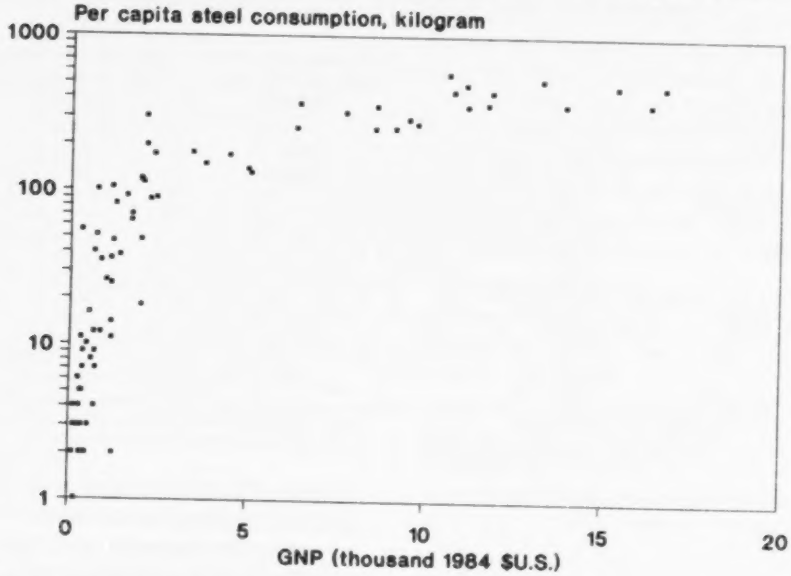
[80] Maurice Y. Meunier and Oscar de Bruyn Kops, op. cit., footnote 75; Sven Eketorp, "Energy Considerations of Classical and New Iron- and Steel-Making Technology," *Energy*, vol. 12, No. 10/11, 1987, pp. 1153-1168.

[81] Maurice Y. Meunier and Oscar de Bruyn Kops, op. cit., footnote 75.

[82] Li Taoping, "Cement Industry in China," *Rock Products*, February 1985, p. 32.

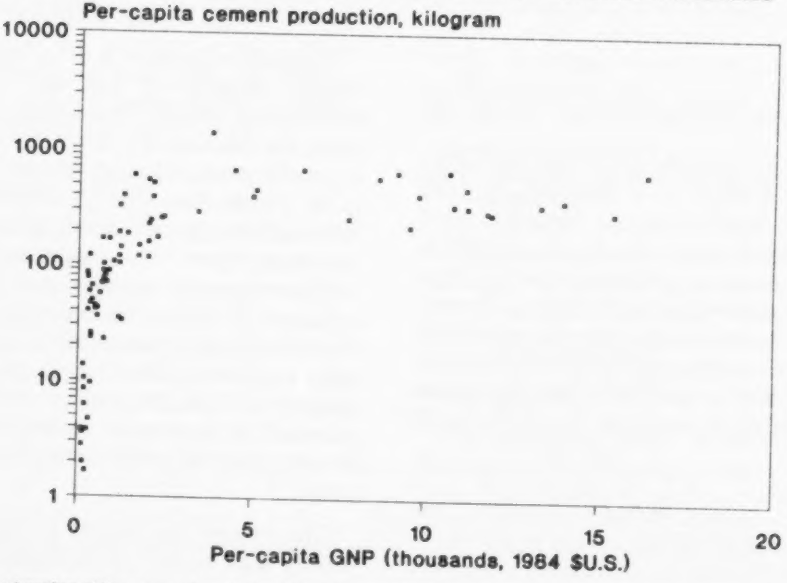
Figure 3-14—Per-Capita Steel Consumption v. GNP for Various Countries



The saturation of the steel market at higher income levels is readily seen in linear or logarithmic plots. It is shown here in a semi-log plot so as to better display both low-end and high-end data. Each data point represents a country.

SOURCE: United Nations, *Statistical Yearbook 1985/86* (New York, NY: 1988), pp. 550-552, table 130.

Figure 3-15—Per-Capita Cement Production v. GNP for Various Countries



The saturation of the cement market at higher income levels is readily seen in linear or logarithmic plots. It is shown here in a semi-log plot so as to better display both low-end and high-end data. Each data point represents a country.

SOURCE: United Nations, *Statistical Yearbook 1985/86*, (New York, NY: 1988), pp. 524-526, table 116.

Table 3-11—Average Energy Intensities of Building Materials (megajoules per kilogram)

Material	Energy intensity
Concrete aggregate	0.18
Concrete	0.80
Brick and tile	3.7
Cement	5.9
Plate glass	25.0
Steel	28.0

SOURCE: Mogens H. Fog and Kishore L. Nadkarni, World Bank, "Energy Efficiency and Fuel Substitution in the Cement Industry With Emphasis on Developing Countries," technical paper No. 17, 1983.

of raw materials, plant management and operating conditions, and other factors. The performance of cement plants in developing countries also varies widely and is difficult to characterize simply. Many plants approach the efficiency of those in the industrialized countries, depending on when they were built and the conditions under which they are operated. Others show significant inefficiencies—using 25 to 50 percent more energy than efficient plants of the same type and with the same quality of raw materials input.[83]

Mechanical Drive

Traditional Drive Power

The productivity of people in many rural and poor urban areas of developing countries is now limited by their reliance on human and animal muscle power for water pumping, grain grinding, agricultural activities, transportation, and small industry. When only muscle power is available, many hours can be spent simply on "enabling" activities, such as hauling water or grinding grain, rather than on directly economically productive activities. Productive activities themselves are sharply limited by the efficiency and total output of muscle power. If the productivity of people in rural areas of developing countries is to be increased, modern motor drive technologies and supporting infrastructures must be made available at affordable costs. As these technologies are adopted, energy use—especially electricity—will increase rapidly.

Table 3-12—Energy Intensities of End Products Using Alternative Building Materials (megajoules per square meter)

Structure	Concrete	Steel	Asphalt	Brick
Building wall	400	—	—	600
Bridge (per m^2)	4,000	8,000	—	—
Roadway (per m^2)	800	—	3,000	—

— Not applicable or not available.

SOURCE: Mogens H. Fog and Kishore L. Nadkarni, World Bank, "Energy Efficiency and Fuel Substitution in the Cement Industry With Emphasis on Developing Countries," Technical Paper No. 17, 1983.

A person's power output and energy efficiency are low. The basal metabolism of a person is about 100 watts; for each unit of work output, an additional 4 to 5 units of food energy must be consumed.[84] Working 8 hours a day at a rate of 50 watts of output, a person consumes about 15 megajoules (MJ) of energy and produces 1.5 MJ of work output, for a daily (24-hour) average efficiency of 10 percent.[85]

Much of the labor expended in developing countries is not directly productive, but is instead for "enabling" activities—that is, domestic chores. Hauling water from the village well can take 0.5 to 3 hours per household each day, with a corresponding energy input in the form of food of 0.3 to 3.0 MJ.[86] The poorest households must often go further and thus have less available time to haul water, resulting in much lower water usage even with greater effort (see table 3-13). Water could instead be pumped by a motor and piped to the home using just 3 to 5 percent as much energy.[87] For electricity priced at $0.10 per kWh, the direct energy cost for

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[83] Mogens H. Fog and Kishore L. Nadkarni, *Energy Efficiency and Fuel Substitution in the Cement Industry With Emphasis on Developing Countries* (Washington, DC: World Bank, 1983), see figure 5-1, p. 39.

[84] W. Edmundson, Energy Research Group, International Development Research Center, Ottawa, Canada, "Is There a Vicious Cycle of Low Food Energy Intake and Low Human Output?" July 1984 (Mimeo); Christopher Hurst, Energy Research Group, International Development Research Center, Ottawa, Canada, "Human and Animal Energy in Transition: The Changing Role of Metabolized Energy in Economic Development," June 1984 (Mimeo); Roger Revelle, "Energy Use In Rural India," *Science*, vol. 192, June 4, 1976, pp. 969-975.

[85] For a countercase, see G.M.O. Maloiy et al., "Energetic Cost of Carrying Loads: Have African Women Discovered an Economic Way?" *Nature*, vol. 319, Feb. 20, 1986, pp. 668-669.

[86] In a study of Gujurat, India, the time required to fetch water was found to vary from 0.5 hour to more than 3 hours per day, with an energy use of 100 to 800 kcal/day. Household washing takes 4.5 to 6.3 hours per week and is as strenuous as hauling water. Girja Sharan (ed.), *Energy Use in Rural Gujurat*, op. cit., footnote 37.

[87] It is often argued that the social interaction provided by activities such as foraging for fuelwood, hauling water, grain grinding, and others is an important element of village life and should not be tampered with naively. One notes, however, that village women spend 10 to 12 hours per day in such activities. Surely they would not object to such social interaction while having a leisurely cup of tea instead.

Table 3-13—Average Daily Household Consumption of Water, Gujurat, India

Class	Consumption (liters per day)
Landless	80
Less than 2 ha	126
Less than 2-4 ha	134
Less than 4-10 ha	161
More than 10 ha	256

SOURCE: Girja Sharan (ed.), *Energy Use in Rural Gujurat* (New Delhi: Oxford and IBH Publishing Co., 1987).

the typical 1.5 hours spent hauling water would be just one-fifth of a penny ($0.002). Thus, lack of access to capital has significant impacts on labor and energy use.

Similarly, in Africa, to pound maize or millet by hand can take 1 to 2 person-hours per day per household.[88] This requires perhaps 1 MJ of energy (at 300 watts of input). A typical motor-driven mill can do the same job in a minute or less, with an energy expenditure of less than 0.2 MJ—or 0.05 kWh. This is less than one-half of a penny ($0.005) worth of direct energy (at $0.10 per kWh) for 1 to 2 hours' worth of hard labor. The capital costs in these cases, of course, are a serious barrier to investment; but with the time saved, the person might have done something more productive, such as make handicrafts for market.

The advantages of mechanical processing of grains has led to a rapid transition in many parts of the world. In Java, Indonesia, for example, the fraction of rice processed by hand dropped from perhaps 80 percent to less than 40 percent between 1971 and 1973.[89] This freed many women from the chore of grinding grain; it also cost many of the poorest households an important source of income earned by hand pounding rice for wealthier households.[90] The introduction of mechanical rice milling in Bangladesh in the early 1980's was estimated to displace an additional 100,000 or more poor women per year from their traditional part-time employment at hand pounding rice. For the poorest, landless women, this represented roughly half of their annual income and 15 percent of family income.[91]

The power output and efficiency of draft animals are similarly limited in performing typical farm tasks. A typical 500-kg ox or buffalo has a basal metabolic rate of about 1,000 watts.[92] Average net output over a 6-hour working day is typically 250 watts, and the net efficiency while working is 29 to 39 percent, which drops to about 10 percent over the 24-hour working day. A typical draft animal might work just 40 days per year as many of the jobs formerly done by draft animals—pumping water, crushing sugar cane, hauling goods to market—have already been taken over by modern motor-driven equipment. At such a low rate of usage, the efficiency of a draft animal is 2 percent or less on an annual basis. These efficiencies are raised somewhat when the value of the animal's dung, milk, meat, and leather is included.[93]

The low power output and efficiency of a draft animal severely restricts the potential work that can

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[88] Prabhu Pingali, Yves Bigot, and Hans P. Binswanger, *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa* (Baltimore and London: Johns Hopkins University Press for the World Bank, 1987); Mead T. Cain, "The Economic Activities of Children in a Village in Bangladesh," *Population and Development Review*, vol. 3, No. 3, September 1977, pp. 201-227; A.S. Bhalla, "Choosing Techniques: Handpounding V. Machine-Milling of Rice: An Indian Case," *Oxford Economic Papers*, vol. 17, No. 1, March 1965, pp. 147-157; Margaret Haswell, *Energy for Subsistence* (London: MacMillan Press, Ltd., 1981).

[89] C. Peter Timmer, "Choice of Technique in Rice Milling on Java," Carl K. Eicher and John M. Staatz (eds.), *Agricultural Development in the Third World* (Baltimore, MD: Johns Hopkins University Press, 1984), pp. 278-288. See also A.S. Bhalla, "Choosing Techniques: Handpounding V. Machine-Milling of Rice: An Indian Case," op. cit., footnote 88.

[90] William L. Collier et al., "A Comment," in Carl K. Eicher and John M. Staatz (eds.), *Agricultural Development in the Third World* (Baltimore, MD: Johns Hopkins University Press, 1984).

[91] Gloria L. Scott and Marilyn Carr, World Bank, "The Impact of Technology Choice on Rural Women in Bangladesh: Problems and Opportunities," Staff Working Paper No. 731, 1985.

[92] Peter Lawrence and Anthony Smith, "A Better Beast of Burden," *New Scientist*, Apr. 21, 1988, pp. 49-53. Oxen and buffaloes use 2 joules per meter traveled per kg of body weight (2 J/m/kg). An animal weighing 500 kg and walking at 1 m/s will use an extra kW, approximately doubling its resting metabolic rate. Most agricultural animals move at 0.6 to 1.1 m/s. Animals use more energy for carrying loads than they do for carrying their own weight, ranging from 2.6 to 4.2 J/m/kg. See also A.R. Rao, "Bioenergetics of Bullock Power," *Energy*, vol. 9, No. 6, 1984; N.H. Ravindranath et al., "An Indian Village Agricultural Ecosystem—Case Study of Ungra Village. Part I. Main Observations," op. cit., footnote 5; Amulya Kumar N. Reddy, "An Indian Village Agricultural Ecosystem—Case Study of Ungra Village. Part II. Discussion," op. cit., footnote 5. They estimate the efficiency of an Indian bullock as 8.7 percent when working full time, or if working just 20 days per year as observed, the bullock would have an overall efficiency of 0.5 percent.

[93] N.H. Ravindranath and H.N. Chanakya, "Biomass Based Energy System for a South Indian Village," *Biomass*, vol. 9, No. 3, 1986, pp. 215-233. Draft animal efficiency is 3.5 percent, including nitrogen in manure for fertilizer. Without nitrogen, the efficiency is 2.0 percent.

Table 3-14—Industrial Electricity End Use in Brazil, 1984

Industry	Percent of total industrial electricity consumption	Fraction of subsector total for each end use (percent)					
		Motor	Process heat	Direct heat	Electro-chemical	Light	Other
Nonferrous metals	20.9	32	1	35	32	1	—
Iron and steel	12.4	1	—	98	—	1	—
Chemicals	11.9	79	5	4	9	3	—
Food and beverage	9.0	6	78	16	—	1	3
Paper and pulp	6.5	87	8	2	—	3	—
Mining/pelletization	5.6	50	—	49	—	1	—
Textiles	5.3	89	4	1	—	5	1
Steel alloys	4.8	7	—	92	—	1	—
Ceramics	3.9	65	—	34	—	1	—
Cement	2.7	91	—	6	—	3	1
Other	17.0	76	2	16	—	5	1
Total[a]	100.0	49	10	32	—	2	—

— Not available or not applicable.

[a] Total industrial electricity use was 105 terawatthours.

SOURCE: Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report prepared for the Office of Technology Assessment, March 1990.

be done. To irrigate a 1-hectare rice crop, for example, requires the work output of two bullocks, which in turn require the fodder produced from 2 hectares of crop.[94] By himself, the individual farmer could not, however, pump this much water by hand in an entire year.

Modern Drive Technologies

Electric motor drive consumes an estimated 58 to 68 percent of the electricity used in the United States, and an even higher percentage in the industrial sector alone.[95] Motor drive is similarly important in developing countries (see tables 3-14 and 3-15). Electric motors are the workhorses of modern industrial society. They run home refrigerators; drive office air conditioners; power industrial pumps, fans, and compressors; and keep city water supplies flowing.

The efficiency, convenience, and high degree of control of electric motors provide dramatic efficiency and productivity improvements in industry.[96] This led to a rapid transition in the industrialized countries from water- and steam-powered drive to electric drive in the early 1900's;[97] and the electricity intensity of industry continues to increase today in industrialized as well as developing countries.

The efficiency of electric motors is generally fairly high in the industrialized countries, but can be significantly lower in developing countries due to the use of lower quality materials for construction and improper techniques for maintenance, repair, and rewind.[98] Figure 3-16 compares the efficiency of electric motors in Brazil, India, and the United States.

Higher efficiency motors are sometimes readily available in developing countries but cannot be used because of the poor quality of the electric power available. In Brazil, for example, the largest manufacturer of small motors exports more efficient models than those sold at home. These high-efficiency motors[99] cannot be used in Brazil due to the excessive variation in the power line voltage.

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[94] Geoffrey Barnard and Lars Kristofferson, *Agricultural Residues as Fuel in the Third World* (London: Earthscan, 1985).

[95] Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems," in *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

[96] Samuel F. Baldwin, "The Materials Revolution and Energy-Efficient Electric Motor Drive Systems," *Annual Review of Energy*, vol. 13, 1988, pp. 67-94; W.D. Devine, Jr., "Historical Perspective on Electrification in Manufacturing," S. Schurr and S. Sonenblum (eds.), *Electricity Use: Productive Efficiency and Economic Growth* (Palo Alto, CA: Electric Power Research Institute, 1986).

[97] Samuel F. Baldwin, "The Materials Revolution and Energy Efficient Motor Drive Systems," *Annual Review of Energy*, vol. 13, 1988, p. 67-94.

[98] Samuel F. Baldwin and Emile Finlay, Princeton University, Center for Energy and Environmental Studies, "Energy-Efficient Electric Motor Drive Systems: A Field Study of the Jamaican Sugar Industry," working paper, No. 94, February 1988. In particular, when motors are rewound they are sometimes simply put on an open fire to burn the insulation off the windings rather than in temperature-controlled ovens. This can damage the insulation between the core laminations and lead to greater losses.

[99] The efficiency of these motors is equivalent to the standard efficiency in the industrialized countries.

Table 3-15—Projected Electricity Consumption in India by Sector and End Use, 1990
(percent of total national electricity use)

		Industrial process				Space conditioning		Appliances		
Sector	Total[a]	Motor drive	Electrolysis	Process heat	Lighting	Cooling/ ventilation	Heating	Refrigeration	Other	Miscellaneous
Residential	13.0	—	—	—	4.2	3.5	—	1.5	1.0	2.9
Urban	10.4	—	—	—	2.9	2.9	—	1.2	1.0	2.4
Rural	2.6	—	—	—	1.3	0.5	—	0.3	—	0.5
Commercial	11.2	—	—	—	4.8	1.6	1.5	0.4	0.8	2.1
Agriculture	18.4	18.4	—	—	—	—	—	—	—	—
Industrial	54.8	33.4	10.8	5.5	5.1	—	—	—	—	—
Primary metals[b]	17.2	6.4	6.9	3.0	0.9	—	—	—	—	—
Chemicals	13.8	8.8	3.6	0.1	1.3	—	—	—	—	—
Textiles	10.2	7.8	—	0.4	2.1	—	—	—	—	—
Coal, cement	6.8	5.8	—	0.5	0.4	—	—	—	—	—
Secondary metals[c]	3.4	1.5	0.2	1.4	0.2	—	—	—	—	—
Paper	3.4	3.0	—	0.1	0.3	—	—	—	—	—
Railway traction	2.6	2.6	—	—	—	—	—	—	—	—
Total	100.0	54.4	10.8	5.5	14.5	5.1	1.5	1.9	1.8	5.0
Motor drive	61.4	54.4	—	—	—	5.1	—	1.9	—	

— Not available or nor applicable.

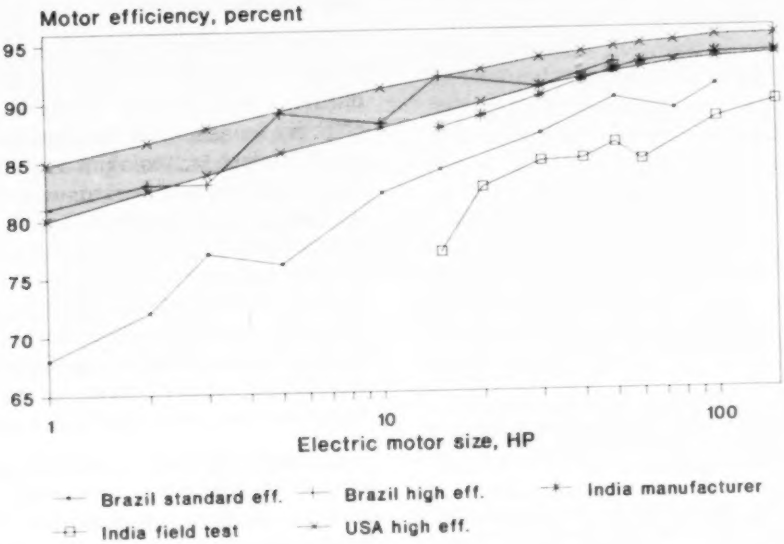
[a] Total national consumption is projected to be 249.1 terawatthours in 1990.

[b] Aluminum, nonferrous, iron, and steel.

[c] Iron and steel.

SOURCE: Ahmad Faruqui, Greg Wikler, and Susan Shaffer, "Application of Demand-Side Management (DSM) To Relieve Electricity Shortages in India," contractor report prepared for the Office of Technology Assessment, April 1990.

Figure 3-16—Efficiency of Electric Motors in the United States, Brazil, and India



This figure shows the efficiency for motors in Brazil, India, and (high-efficiency only) the United States. Note the large difference in motor efficiency as measured in field tests and as cited by manufacturers in India.

SOURCES: ***United States***: John C. Andreas, *Energy-Efficient Electric Motors* (New York, NY: Marcel Dekker, 1982). ***Brazil***: Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report prepared for the Office of Technology Assessment, March 1990; ***India***: S. Anand, and V.S. Kothari, *Characterization of Electric Motors in Industry and Energy Conservation Potential in India* (New Delhi, India: Tata Energy Research Institute, no date).

This firm has also developed motors with efficiencies comparable to the highest performance motors in industrialized countries.[100]

Although the efficiency of electric motors themselves can be quite high, the efficiency of the overall system is generally low. For example, the conversion of coal to electricity typically results in the loss of two-thirds of the input coal energy. There are additional losses throughout the system, with the resulting net output as low as 5 percent of the input energy (see figure 3-17). Significant energy savings are possible through the use of better technologies and better control strategies throughout the system.

Barriers to Efficiency Improvements

A number of factors limit the efficiency, productivity, and performance of industrial operations in developing countries: plants that are too small to be efficient; technologies that are of low quality and often obsolete; raw materials that are of low quality; inadequate national infrastructures; lack of foreign exchange to purchase critical components not available locally; and a lack of skilled technicians, engineers, and managers.

The average U.S. paper mill, for example, has an annual capacity of 100,000 tons, whereas in Latin America, Africa, and Asia (except Japan), the average capacities are 18,000, 9,000, and 5,000 tons, respectively. These smaller scales can lead to significant inefficiencies. Studies indicate that a paper mill with an annual capacity of 30,000 tons can consume from 30 percent to as much as 100 percent more energy/steam respectively per unit output than a mill with a capacity of 150,000 tons.[101] In addition, a variety of energy-conserving technologies, such as waste heat recovery systems and

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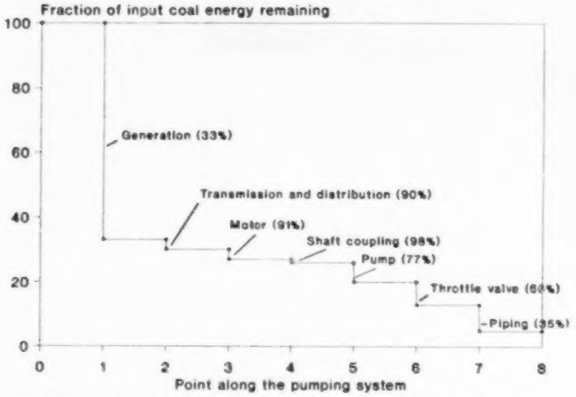
[100] Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report prepared for the Office of Technology Assessment, March 1990.

[101] Andrew J. Ewing, "Energy Efficiency in the Pulp and Paper Industry with Emphasis on Developing Countries," World Bank technical paper, No. 34, Washington, DC, 1985, p. 45.

Figure 3-17—Energy Losses in an Example Electric Motor-Driven Pumping System in the United States



This figure shows the useful energy remaining at each stage of a pumping system. The values in prentheses are the efficiencies of the particular device at each stage.

SOURCE: Samuel F. Baldwin, *Energy-Efficient Electric Motor Drive Systems*, in *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

cogeneration systems, become financially less attractive or even uneconomical at smaller scales.

The raw materials available to industries in developing countries are often of low quality. For example, coal resources in India are poor, providing blast-furnace coke with an ash content that typically ranges from 21 to 27 percent. This lowers the energy efficiency of the steelmaking process as well as potentially interfering with steel production.[102]

Inadequate national infrastructures also reduce efficiency and productivity. Frequent electric power brownouts or blackouts are particularly damaging. In Ghana, for example, the GIHOC Brick and Tile Co. had 152 hours of electricity outages in 1986. When an outage occurs, the fuel oil feed to the kiln burners is cut off and the fire must be stoked with wood. This is a haphazard process and significantly reduces the quality of the fired bricks.[103]

The lack of foreign exchange to buy spare parts can also be a serious handicap. This has been an important factor in the decline of the Tanzanian cement industry, which operated at just 22 percent of rated capacity in 1984.[104]

Assistance may be useful at several levels. The efficiency and productivity of traditional rural industries might be significantly increased in a cost-effective manner with the introduction of a limited set of modern technologies and management tools. To do this, however, is extremely difficult due to the small and scattered nature of traditional rural industries and the large extension effort needed to reach it. Large industry in developing countries has many of the same needs—technical, managerial, and financial assistance—but can be reached more readily. International aid agencies and a few non-governmental organizations are providing such assistance to the extent that their funds allow.

Dramatic improvements in the energy efficiency and productivity of basic materials processing technologies are also still possible—even beyond the levels currently achieved in the industrialized countries. Research is going on in this area, but much more could be done. Much of the current research is focused on higher value-added specialty materials and high-grade finishing rather than on primary processing.[105] Developing countries, however, have little capital to undertake the research needed to improve their industrial processes, and few international agencies support research of this kind.

The Traction (Agricultural) and Transportation Sectors

Traction and Agriculture

Agriculture entails a series of operations: soil preparation, sowing, weeding, harvesting, and post-harvest storage. In traditional agriculture, these operations are performed by manual labor with, in some cases, assistance from animals. As agriculture increases in scale and is commercialized, many of these operations are done by machines.

Agriculture is by far the largest employer and goods-producing economic sector in the poorer developing countries. In sub-Saharan Africa, for example, 75 percent of the work force is engaged in agriculture, compared to just 2 percent in the United States. Agriculture also provides a significant fraction of GDP in developing countries—one-third of GDP for the nearly 3 billion people in low-income countries[106] (see table 3-16).

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[102] Energy and Environmental Analysis, Inc., "Conserving Process Heat in Primary Industries of India and China," contractor report prepared for the Office of Technology Assessment, April 1990.

[103] UNDP/World Bank Energy Sector Management Assistance Program, "Ghana: Energy Rationalization in the Industrial Sector," June 1988.

[104] D.F. Stewart, and B. Mubegi, "Strategies for Meeting Tanzania's Future Cement Needs," *Natural Resources Forum*, November 1989, pp. 294-302.

[105] Robert H. Williams, Princeton University, personal communication, Feb. 1, 1989.

Agriculture in the lowest income countries is largely by small, family farms using human and animal power and organic fertilizer with little access to or knowledge of modern inputs such as chemical fertilizers, hybrid seeds, or mechanical drive. Ethiopians, for example, use on average just 4 kg of chemical fertilizer per hectare of cropland, while the English use 368 (see table 3-16). Low soil fertility and inadequate or irregular rainfall sharply limit the productivity of low-input farms in developing countries.

There is a general trend toward larger farms, greater mechanization, and greater use of commercial inputs in many developing countries, resulting in greater productivity but at the cost of greater direct and indirect energy inputs. India, for example, nearly doubled its irrigated area between 1950 and 1984 in order to reduce its vulnerability to poor monsoons.[107] Increased irrigation and use of high-yield variety crops have contributed to increases in both absolute and per-capita agricultural production.[108]

China has similarly moved toward greater mechanization and use of modern inputs. Agriculture in China is sharply constrained by land availability—only about 10 percent of the land can support crops—yet per-capita production increased by 18 percent from 1979 to 1983 with little increase in cultivated area.[109] Improved water control and distribution, increased use of tractors and fertilizers, and the adoption of new crop varieties contributed to this achievement.[110]

Traditional Shifting Agriculture

Traditional shifting agriculture begins with forest-fallow systems, in which plots of forest land are cleared and cultivated for a few years and then left fallow for 20 years or more. Clearing by fire requires little labor, and stumps are left for rapid regrowth during fallow. Because the ground underneath tree cover is soft, no further labor is required before sowing, and because the forest cover has long suppressed weeds, few seeds remain and little weeding is needed. Such burning does, however, effectively lead to very large agricultural energy intensities due to the large amount of forest cover that is burned off.[111]

With increasing population density, the fallow period becomes shorter. As a result, regrowth during the fallow period is reduced to bush, and finally to grass. Since fire does not kill roots, extensive hoeing and weeding become necessary. Inputs of organic fertilizer are needed to maintain soil fertility, and there is a shift from simple addition of organic material to more complex composting and manuring techniques. Further increases in population lead to annual cultivation and eventually multiple cropping. (In the humid tropics, however, soils tend to be poor and easily eroded and leached, and the potential for continuous cultivation is limited.[112]) As the need for hoeing and weeding increases it becomes advantageous to go to the extra effort of destumping the land and obtaining, training, and maintaining animals or mechanical agricultural technology.[113]

There are a number of potential advantages associated with the use of animal or mechanical traction for agriculture. Properly done, tillage improves the condition of the soil for crop growth—increasing porosity, aeration, root penetration, and water infiltration while reducing evaporation. Ex-

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[106] World Bank, *World Development Report 1990* (New York, NY: Oxford University Press, 1990).

[107] Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988*, op. cit., footnote 56, p. 128.

[108] Food and Agriculture Organization of the United Nations, "The State of Food and Agriculture, 1984," Rome, Italy, 1985, p. 137.

[109] Ibid.

[110] C. Howe, *China's Economy* (New York, NY: Basic Books, Inc., 1978).

[111] A. Terry Rambo, "Why Shifting Cultivators Keep Shifting: Understanding Farmer Decision-Making in Traditional Agroforestry Systems," *Community Forestry: Some Aspects*, UNDP THA/81/004 (Bangkok, Thailand: Environment and Policy Institute, East-West Center, Honolulu, and UNFAO Regional Office for Asia and the Pacific, 1984).

[112] Prabhu Pingali, Yves Bigot and Hans P. Binswanger, *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa*, op. cit., footnote 88.

[113] Prabhu Pingali et al., ibid. The exact transition point from hand to animal and then tractor technology will, of course, depend on numerous factors, including how difficult the soil is to work; the value of milk, meat, hides, and other services provided by cattle; the use of manure; the cost of training and maintaining animals; the cost of destumping and otherwise preparing fields and weeding; the length of time that animals can be used; the risk of disease such as trypanosomiasis (transmitted by the tsetse fly); and many others.

Table 3-16—Agricultural Indicators for Selected Countries

Country	GNP/Cap (1987)	Agricultural GDP as percent of total GDP	Agricultural employment as percent of total employment	Percent of farms larger than 5 ha	Fertilizer (kg/ha)	Crop yields (kg/ha)	
						Cereal	Roots/tubers
Ethiopia	130	45	—	4	4	1,081	2,827
Zambia	250	13	—	—	14	1,747	3,687
India	300	30	61	9	43	1,590	14,268
China	290	26	57	—	176	3,891	15,614
Brazil	2,020	10	36	63	35	1,719	12,072
UK	10,420	2	2	83	368	6,081	36,072
U.S.A.	18,530	2	2	90	101	4,618	31,215

— Not available or not applicable.

SOURCES: World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989).
Food and Agriculture Organization of the United Nations, *The State of Food and Agriculture 1984* (Rome: FAO, 1985), pp. 163-165, 178-180.
Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook 1988* (New Delhi, India: Tata Energy Research Institute, 1989), p. 123.
World Resources Institute, *World Resources 1988-89* (New York, NY: Oxford University Press, 1988), pp. 272-277.

Box 3-A—The One-Ox Plow[1]

Many farmers in developing countries are unable to support the two draft animals needed to pull a traditional plow. Although half of the households in Bangladesh keep cattle, only a quarter have two or more. In Ethiopia, only a third of the farmers own two draft animals—and many of these are lost in the periodic droughts. At peak cultivation times, these farmers must then rent or borrow a second animal and may be delayed in planting their crops, which depend critically on catching the sparse and irregular rains in a timely manner—both for making maximum use of the nitrogen released with the first rains (see ch. 2) and for reaching maturity with the last rains.

Researchers at the International Livestock Center for Africa (ILCA) in Addis Ababa, Ethiopia, responded to this situation by redesigning the traditional double yoke for a single ox: experiments showed that one ox could pull with 70 percent of the force of two.

In the field, however, Ethiopian farmers quickly converted the one-ox plows back into the traditional two-ox form. On examination, researchers found that the traditional two-ox form had a number of advantages. Farm oxen were not as well fed nor as strong as those which had been tested at the ILCA headquarters and could not pull as hard; and two oxen were able to steady each other when one stumbled. The rigid coupling of the traditional two-ox plow also enabled the farmer to steer the oxen and to shift some of the weight of the plow to the oxen during a turn. In contrast, the single ox yoke used a flexible rope harness which reduced the farmer's ability to steer the animals and forced him to carry the full weight of the plow when turning. The one ox plow also had a skid to regulate the depth of the cut: it broke easily but could not be repaired by the farmers themselves.

Further, where the quality of the feed is very poor—a common situation in many tropical areas—working animals are unable to compensate for their energy expenditure by eating more and consequently lose weight. A working animal also has a 10 percent higher basal metabolic rate than a nonworking animal—requiring more food just for maintenance. In this case, it may be better to use two oxen to do "what little they can without losing too much weight rather than to have one ox which soon becomes exhausted beyond recovery."

As one researcher at the ILCA noted, "It might have occurred to us that if Ethiopian farmers hadn't invented something as simple as the one-ox plow in 3,000 years of agriculture, they probably had reasons."

Some have similarly thought that the same animal might be used to provide both labor and milk. Experiments in Costa Rica showed that cows could, in fact, provide both—if fed adequately. Tropical pastures, however, are not adequate. To provide the animal a sufficient diet for such a high rate of energy expenditure required concentrated feed supplements such as grain. This could create a direct conflict over food between draft cows and people in many parts of the world.

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[1] Debora MacKenzie, "Ethiopia's Hand to the Plough," *New Scientist*, Oct. 1, 1987, pp. 52-55; Peter Lawrence and Anthony Smith, "A Better Beast of Burden," *New Scientist*, Apr. 21, 1988, pp. 49-53; A.K.M. Abdul Quader and K. Ikhtyar Omar, Commonwealth Science Council, "Resources and Energy Potentials in Rural Bangladesh," technical publication series No. 191, London, 1986.

periments show that yields can be increased by plowing.[114] In practice, however, little increase is observed as farmers tend instead to focus on increasing cultivated area[115] or on saving labor, rather than improving the quality of their tillage. In West Africa, the soils are so hard they often cannot be plowed (without damage to equipment) until the rains begin, but then any delay reduces the available growing time and risks a shortage of water when plants reach maturity.[116]

Peasant farmers have responded to their often difficult circumstances in varied ways—both logical (see box 3-A) and frequently ingenious. For example, around 1925-1930, animal traction began to be used in northwestern and central Senegal and northern Nigeria for peanut cultivation. The light, sandy soils of Senegal do not require plowing, and as the growing season is so short, rapid planting of peanuts while the soil is moist is essential. Consequently, seeders are used by the peasants so that larger areas can be cultivated within the available time. Horses are used instead of oxen, since the greater power of oxen is not needed (there is no plowing) and horses are faster, further increasing the planted area. In Nigeria, where peanuts are grown in mid-slope regions on soils highly susceptible to erosion, ox-drawn ridgers are used to control the erosion.[117]

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[114] Prabhu Pingali, Yves Bigot, and Hans P. Binswanger, *Agricultural Mechanization and the Evolution of Farming systems in Sub-Saharan Africa*, op. cit., footnote 88; Peter Munzinger, *Animal Traction in Africa* (Eschborn, West Germany: GTZ, 1987), p. 279.

[115] In Senegal the average expansion of agricultural area by the introduction of draft animals to smallholders is 100 to 160 percent; in Mali the average expansion is 150 to 200 percent. Peter Munzinger, *Animal Traction in Africa*, op. cit, footnote 114, p. 287.

[116] Prabhu Pingali et al., op. cit., footnote 88

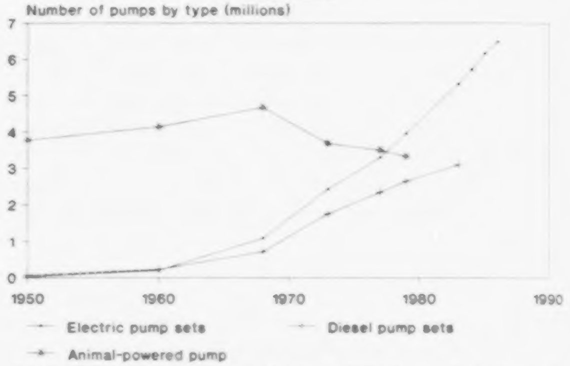
Modern Commercial Agriculture

As population grows agricultural productivities must be raised. Modern inputs are needed to achieve this. Commercial fuel inputs to agriculture include mechanized land preparation, mechanized irrigation, and synthetic fertilizers.[118]

The degree of mechanization varies widely, but generally increases with per-capita income. Mechanization reduces the time and labor needed for preparing, planting, and harvesting crops. In favorable areas, it also aids double cropping. The tractors themselves come in many forms—in China the most popular is probably the "Worker-Peasant," a 7-hp garden tractor. In India, where the number of tractors almost doubled from 1972 to 1977,[119] the most popular is a 30-hp diesel.

Irrigation is most commonly done with either electric motor or diesel driven pumps. Electric pumps are quite reliable (although subject to interruptions in the electric power grid) and convenient, and are often the lowest cost alternative. Diesel-electric pumping systems, in which diesel generators produce electricity that is then used to drive electric pumps, and direct diesel and gasoline-powered pumps are more often used where no electric grid is available. These are much less mechanically dependable than electric pumps.

Figure 3-18—Use of Agricultural Pumpsets in India, 1950-1990



SOURCE: Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988* (New Delhi, India: 1989), footnote 56.

In China, irrigation is a significant consumer of electricity. It is estimated that 70 percent of the electricity consumed in rural areas is for irrigation, with the remainder used for food processing, various rural industries, and lighting.[120] In India, the number of electric pump sets for irrigation has grown rapidly (see figure 3-18), and the electricity consumption for these pump sets has gone from 4,470 GWh in 1970-71 to 23,420 GWh in 1985-86. The number of diesel pump sets has also grown, but they still are fewer in number than the electric units.[121]

Transportation

The transportation sector accounts for a quarter or more of total commercial energy use in most developing countries—India and China being the most notable exceptions (see table 3-1). Most of this transport energy is from oil. Energy use for transportation in the developing world is expected to grow rapidly in the future, as increasing urbanization and incomes (see figure 3-19) lead to increased demand for transportation services. This will increase the outflow of scarce foreign exchange for the oil-importing countries, and will also require considerable investment in roads and related infrastructure.

Transportation can be provided by air, rail, road, or water. In most of the developing world, as well as in the industrialized world, road technologies provide most transport services. Notable exceptions are India and China, which have large rail networks.

In rural and poor areas of the developing world, walking is the principal transport "technology." The advantages of walking are many—it requires no capital investment, it is not restricted to roads, and

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[117] Ibid.

[118] This excludes energy used for fertilizer production and that used for crop preparation, both of which we include under industrial energy use.

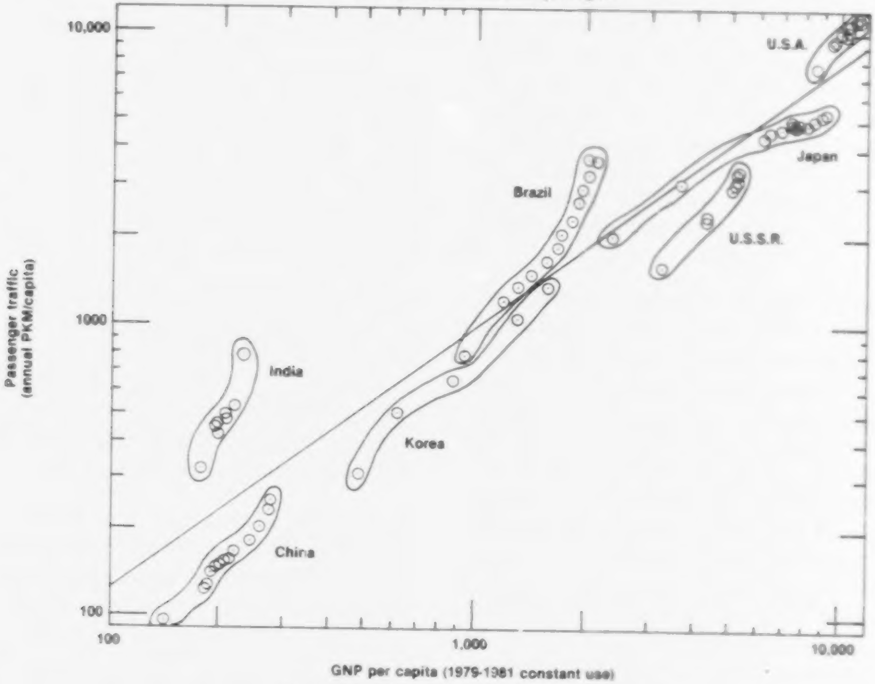
[119] Tata Energy Research Institute, *TEDDY 1988*, op. cit., footnote 56, p. 137.

[120] C. Howe, *China's Economy*, op. cit., footnote 110, p. 88.

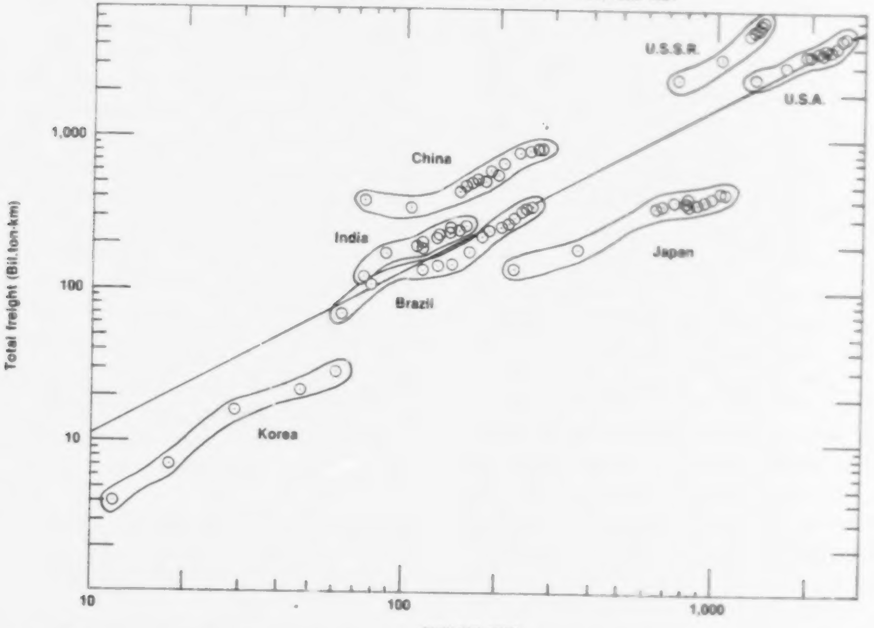
[121] In 1983/84, for example, there were about 5.3 million electric pump sets and 3.1 million diesel pump sets in India. Some of these diesel units were used as backups for the electric units. Tata Energy Research Institute, *TEDDY 1988*, op. cit., footnote 56, p. 135.

Figure 3-19—Passenger and Freight Transport v. GNP for Selected Countries, 1960-81

Passenger traffic and GNP per capita



Total freight and GNP for selected countries, 1960-1981



This figure shows how passenger and freight transport energy use have increased with GNP for seven countries. The individual data points are for specific years.

SOURCE: J. Venny and L. Uy, "Transport in China," World Bank staff working paper, No. 723, Washington, DC, 1985.

it requires no fossil fuels. On the other hand, it is slow, tiring, and requires energy in the form of food. Animal technologies, such as bullock carts, are sometimes faster, have a much greater freight capacity, and involve less work for people. Capital investment in the bullock and cart is required, however, as well as an operational cost for feed. These two technologies—walking and domesticated animals—are the principal means of transport in many poorer and rural areas, particularly in Africa and Asia.

Bicycles are a popular transport technology, especially in China, where from 50 to 90 percent of urban vehicle trips are made by this mode.[122] The first cost of a bicycle can be a barrier—a new bike costs the equivalent of 7 to 8 months' wages in Tanzania, for example—but in some areas bicycles can be bought on credit. In India, government employees are entitled to loans for vehicle purchase, which can be used to buy a bicycle. Bicycles work well in congested urban areas, where they have some advantages over private automobiles—they are easier to park and store, less expensive to own and operate, and do not contribute to air pollution. Their range and freight capacity, however, are limited.

The technological leap to the internal combustion engine allows for much higher speeds, longer distances, larger freight capacity, and greater comfort. The disadvantages of the internal combustion engine are technological complexity, movement largely constrained to roads, high first cost and operating cost, and environmental damage due to fossil fuel burning. There are also secondary effects, such as injury and death due to accidents and land use for roads and parking. Despite its disadvantages, the internal combustion engine is the dominant transport technology in the industrialized and developing world, and its use is growing rapidly.

Passenger Road Transport Technologies

Mechanized passenger road transport in the developing world is performed by a wide range of technologies, including mopeds, private autos, and buses. Developing countries have only about 1 percent as many autos per person as does the United States (see table 3-17), but their automobile fleets are growing rapidly. Further, the scrappage rate (the fraction of vehicles retired each year) is very low in developing countries, due to the high value placed on any vehicle that runs. Therefore, choices made now as to the energy efficiency of new vehicles in developing countries are doubly important—these vehicles will soon be the majority of the fleet and they will be on the road a long time.

Table 3-17—Passenger Fleet Size and Growth in Selected Countries

Country	Automobiles per 1,000 people, 1986	Average annual growth in automobile fleet size, 1982-86
China	0.7	41.6
India	1.8	8.2
Kenya	8.9	3.2
Thailand	21.9	8.8
Brazil	87.0	8.9
Japan	234.0	3.0
West Germany	444.8	3.3
United States	673.4	2.4

SOURCES: Fleet size and growth from Energy and Environmental Analysis, Inc., "Policy Options for Improving Transportation Energy Efficiency in Developing Countries," contractor report prepared for the Office of Technology Assessment, March 1990. Population from World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989). Figures for the United States include both autos and light trucks; data are from Oak Ridge National Laboratory, *Transportation Energy Data Book*, Edition 10, ORNL-6565 (Oak Ridge, TN: Oak Ridge National Laboratory, September 1989).

Although their technical efficiency (vehicle kilometers traveled per liter of fuel consumed) is lower, vehicles in developing countries average a much higher load factor (persons per vehicle) than those in industrialized countries. Buses are chronically overloaded, and mopeds and motorcycles designed for one often carry two or more. Shared ride technologies, such as jitneys, are commonly filled beyond rated capacity. This increases the efficiency of the transportation system in terms of passenger-kilometers per liter of fuel consumed, but reduces safety and comfort.

The vehicles themselves are often less energy-efficient than those found in the industrialized world. They are often based on designs that emphasize sturdiness and dependability under adverse conditions (poor roads, chronic overloading, little maintenance) over energy efficiency.

Freight Road Transport Technologies

Road freight movement in the developing world is provided mostly by diesel trucks (with the exception of China where much of the truck fleet uses gasoline) and these trucks account for over half

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[122] World Bank, "Gridlock Weary, Some Turn to Pedal Power," *The Urban Edge*, vol. 14, No. 2, March 1990.

Table 3-18—Energy Efficiency of Trucks in Selected Countries

Country/ region	Truck name	Capacity (metric tons)	Energy consumption (megajoules per metric ton per kilometer)
OECD	Mercedes Benz 1217 (1979)	7.0	1.0
OECD	Man-VW 9136 (1980)	5.9	1.0
India	TATA 1201 SE/42	5.0	2.1
India	Ashok Leyland Beaver	7.5	1.6
China	Jiefang CA-10B	4.0	2.3
China	Dongfeng EQ140	5.0	1.8

NOTE: OECD and Indian trucks use diesel, Chinese trucks use gasoline.

SOURCE: J. Yenny and L. Uy, World Bank, "Transport in China," staff working paper No. 723, 1985, p. 70.

the energy used for road transport in the developing world.[123] The movement of freight is required for most economic activity, and in many developing countries the prices of diesel fuel are kept lower than gasoline prices. In the United States, for example, gasoline and diesel prices at the pump are almost the same, while in India diesel is slightly less than half the price of gasoline.[124]

Trucks in the developing world are relatively inefficient, requiring 1.5 to 2.5 times as much energy to move one ton of freight one kilometer as comparable trucks in the OECD countries (see table 3-18). In developing countries, however, trucks must cope with more difficult operating conditions: the roads are typically congested and poorly maintained, aggravating technical inefficiency and accelerating wear.

Rail Technologies

Railroads are significant providers of transport services only in India and China, and in these two countries the rail share of total transport is declining rapidly due to the much faster growth of road transport. In China, for example, the share of passenger traffic using railways dropped from 69 percent in 1965 to 48 percent in 1987. Railway freight transport shows the same trend of decreasing relative use.[125] Similarly, India shows a mode shift toward roads and away from rail for both passenger and freight traffic.[126]

Despite these modal shifts, the rail systems in both countries still account for significant energy use. China and India have extensive rail networks that consume, respectively, 72 percent and 29 percent of transportation energy (see app. 3-A). The Indian rail system, although in relative decline, still carries a significant amount of freight and passengers (see table 3-19), using a mix of steam (being phased out), diesel, and electric locomotives.

Implications for Energy Demand

Road transport—private autos for passengers and trucks for freight—has become the dominant mode of transportation in developing countries. Increases in population, income, and auto ownership rates (autos per person) combine to yield a rapid increase in the number of private vehicles. Increasing urbanization leads to greater congestion, which reduces the efficiency of private vehicles. Urbanization, economic growth, and industrialization require large increases in freight movement, as producers move farther from markets. The net effect of these factors will be an increase in the energy needed to provide transportation services.

Improvements in the energy efficiency of developing world transport systems can be made in several areas. Road-going vehicles in the developing world are less energy-efficient than comparable vehicles in the industrialized world, suggesting that efficiency gains can be made in the vehicles

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[123] Trucks account for 50 to 75 percent of energy consumed for road transport in the developing world, compared to 30 to 35 percent for many industrialized countries. Clell G. Harral, "Meeting the Transportation Aspirations of Developing Countries: Energy and Environmental Effects," *Proceedings of the Energy and Environment in the 21st Century Conference* (Cambridge, MA: Massachusetts Institute of Technology, March 1990).

[124] Energy Information Administration, *International Energy Annual 1988*, DOE/EIA-0219(88) (Washington, DC: U.S. Government Printing Office, 1989).

[125] P. Kuirun and S. Guojie, "Overview of Transport Development in China," paper presented at the New Energy Technologies Transportation and Development Workshop, Ottawa, Canada, September 1989.

[126] Joy Dunkerley, Irving Hoch, Charu Gadhok, Kapil Thukral, "Energy and Transport—The Indian Experience," *Pacific and Asian Journal of Energy*, 1987, pp. 1-12.

Table 3-19—Comparison of Rail Systems in China, India, and the United States

	China	India	United States
Length of rail network (km)	53,000	62,000	235,000
Rail energy use (percent of total transport energy use)	51	27	3
Percent of freight traffic carried by rail	45	47	30
Percent of passenger traffic carried by rail	55	22	1

SOURCES: P. Kuirun and S. Guojie, "Overview of Transport Development in China," paper presented at the New Energy Technologies Transportation and Development Workshop, Ottawa, Canada, September 1989; Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988* (New Delhi, India: 1989); International Energy Agency, *World Energy Statistics and Balances: 1981-87* (Paris: OECD, 1989); Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 10*, ORNL-6565, 1989; Association of American Railroads, *Railroad Facts 1989* (Washington, DC: American Association of Railroads, 1990).

themselves. Improvements in the transportation infrastructure, such as improved roads and reduced congestion, can also increase energy efficiency. Mode choices, such as a movement away from private autos and motorcycles to buses and bicycles, can help. Of course, all these options have benefits and costs: these will be explored later in this OTA study. The important conclusions for this section, however, are that the demand for transportation services is increasing rapidly, technologies in use today are not as efficient as they could be, and the energy impacts of technology choices made today will be felt far into the future.

Conclusion

This survey of energy services and how they are provided in developing countries reveals three common characteristics. First, each service is provided by a wide range of technologies and fuels. Cooking is provided by technologies ranging from open fires to microwave ovens, with a large number of possibilities in between. The range of passenger transport services is similarly wide, varying from foot to jet passenger airplanes. Second, there is in almost all cases a well-established transition between technologies, depending on two main factors—income and availability of fuel supplies. Third, the services are currently being provided by technologies whose efficiency could usually be significantly improved.

The following chapter will examine how the many types of energy used in developing countries—fossil fuels, electricity, and biomass fuels—are provided, including domestic production, imported supplies, the energy distribution system, and the energy conversion sector.

Appendix 3-A—Energy Balances for Selected Developing Countries

The following energy balances begin with International Energy Agency (IEA)[127] energy production, trade, and stock change totals for commercial fuels. This provides a common framework for evaluating individual countries and for comparing different countries. Biomass fuels for the traditional sector are not included in the country-specific IEA data and so are separately added based on country specific field survey data. The year chosen for each country is determined primarily by the year for which the biomass energy data is available.

In contrast to the IEA procedure, energy supply production, conversion, and transformation losses are not separately tallied in the energy balances presented here. Instead, these losses are carried forward into the sectoral breakdowns in proportion to the IEA sectoral breakdown of energy use. This more accurately indicates sectoral energy usage by showing the losses incurred in providing energy to each sector.

Electricity is initially divided into two categories in the following energy balances: nonthermal and thermal. Nonthermal electricity is given in terms of the electric power output—the joule equivalent of kWh. Thermal electricity is given in terms of thermal energy input; losses incurred in generation, transmission, and distribution are kept in the total. Nonthermal and thermal electricity quantities, therefore, can not be directly compared.

The IEA convention for electricity production divides the hydroelectric output in kWh by 0.385 in order to make hydroelectric power appear to be on the same "thermal equivalent" input basis as thermally generated electricity when listed on the basis of fossil fuel input. The IEA subsequently multiplies the sum of hydroelectric "thermal equivalent" and thermal electric inputs by 0.385 to get an electric power output in kWh. Thermal and hydroelectric "thermal equivalent" losses are lumped together as an energy production loss.

This convention of "thermal equivalents" leads to a large misrepresentation in the energy balances for hydro-rich countries such as Brazil. The procedure used here avoids the IEA convention of assigning a thermal equivalent for hydroelectric or other nonthermal power. It also carries the losses in thermal generating plants through to the end-use sectors as noted above. At the sectoral level, the thermal and nonthermal electricity are added together directly to indicate the average amount of energy, including fossil fuel, used by each sector. These figures are shown in brackets to denote that the figure is a sum of nonthermal electricity output and thermal energy input. This procedure lowers the energy supply totals compared to those usually found in the literature.

Percentage breakdowns by end-use sector are based on the IEA data; percentage breakdowns by energy service within end-use sectors are based on country-specific surveys as noted. The end service breakdowns are the best estimates that OTA could make given the poor quality and paucity of available data. These breakdowns are provided here only as an indication of the relative importance of selected energy services; they should not be construed to be a precise quantitative measure of the energy consumed in delivering these services or to be a precise listing of energy services and their interrelationships. Some important energy services and fuel mixes are overlooked in many of the available energy service breakdowns. For example, lighting and the use of traditional fuels are largely left out of the industrial sector. In addition, a number of important energy services are generally left out of the breakdowns: an example might be the use of animals for traction in agriculture and the use of crop residues to feed them.

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[127] International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989).

Table 3A-1—Brazil: Energy Supplies and Services, 1987 Exajoules (10^{18} Joules = 0.9478 Quad) and Percent of National Total

	Fossil fuels			Electricity		Biomass			
Energy supplies	Coal	Oil	Gas	Nonthermal	Thermal	Cane/ alcohol[a]	Wood/ charcoal	Other	Total
Production	0.124	1.55	0.112	0.681	—	0.91	1.39	0.13	4.90
Trade/stock change	0.315	1.040	—	0.023	—	—	—	–0.01	1.37
Electric generation	–0.044	–0.073	—	—	0.117	—	—	—	0.00
Nonenergy	—	–0.167	—	—	—	–0.02	—	—	–0.19
Total energy	0.40	2.349	0.112	(0.821)		0.89	1.39	0.12	6.08
Percent of total	6.6%	38.6%	1.8%	13.5%		14.6%	22.9%	2.0%	100%
Energy services									
Residential	—	0.202	0.007	(0.169)		—	0.48	—	0.86
Residential	—	3.3%	0.1%	2.8%		—	7.9%	—	14.1%
Cooking/heating	—	3.3%	0.1%	0.77%[3]		—	7.9%	—	12.1%
Lighting	—	—	—	0.67%		—	—	—	0.7%
Refrigeration	—	—	—	0.90%		—	—	—	0.9%
Television	—	—	—	0.17%		—	—	—	0.2%
Air conditioning	—	—	—	0.09%		—	—	—	0.1%
Other	—	—	—	0.21%		—	—	—	0.2%
Commercial[c]	—	0.026	0.003	(0.159)		—	0.018	—	0.21
Commercial	—	0.42%	0.05%	2.62%		—	0.3%	—	3.5%
Cooking/heating	—	0.42%	0.05%	0.20%		—	0.3%	—	1.0%
Lighting	—	—	—	1.15%		—	—	—	1.2%
Refrigeration	—	—	—	0.45%		—	—	—	0.5%
Air conditioning	—	—	—	0.52%		—	—	—	0.5%
Other	—	—	—	0.29%		—	—	—	0.3%
Industrial	0.40	0.56	0.10	(0.46)		0.44	0.75	—	2.71
Industrial	6.58%	9.22%	1.65%	7.57%		7.24%	12.3%	—	44.6%
Motor drive	—	—	—	3.71%		—	—	—	3.7%
Process heat	6.58%	9.22%	1.65%	3.18%		7.24%	12.3%	—	40.2%
Lighting	—	—	—	0.15%		—	—	—	0.2%
Electrochemical	—	—	—	0.53%		—	—	—	0.5%
Transport	0.00	1.417	—	(0.005)		0.44	—	—	1.86
Transport	0*	23.3%	—	0.08%		7.24%	—	—	30.6%
Road	—	20.4%	—	—		7.24%	—	—	27.6%
Rail	0*	0.43%	—	0.08%		—	—	—	0.5%
Air	—	1.74%	—	—		—	—	—	1.7%
Other	—	0.77%	—	—		—	—	—	0.8%
Agriculture	—	0.146	—	0.026		—	0.126	—	0.30
Agriculture	—	2.4%	—	0.43%		—	2.1%	—	4.9%

— Not available or not applicable.

( ) data in parentheses is sum of nonthermal energy output and thermal energy input.

[a] The use of bagasse for energy production (cogeneration) is divided proportionately between industrial process heat and road transport. Electricity generation within the cane industry is not given separately.

[b] This is mostly for water heating (10 TWh). Only 0.5 TWh were for cooking.

[c] Excludes public buildings.

SOURCES: Adapted from International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989); and Brazilian Ministry of Mines and Energy, *National Energy Balance for Brazil 1988* (Brasilia, 1988), provided by Howard S. Geller, American Council for an Energy Efficient Economy, Washington, DC, and Sao Paulo, personal communication, Mar. 8, 1990.

Table 3A-2—China: Energy Supplies and Services, 1987 Exajoules (10^{18} Joules = 0.9478 Quad) and Percent of National Total

	Fossil fuels			Electricity		Biomass fuels				
Energy supplies	Coal	Oil	Gas	Nonthermal	Thermal	Crop	Wood	Dung	Biogas	Total
Production	18.15	5.32	0.46	0.33	—	3.4	3.2	0.15	0.03	31.0
Trade/stock change	-0.80	-1.40	—	—	0.00	—	—	—	—	-2.2
Electric generation	-3.15	-0.59	-0.02	—	3.76	—	—	—	—	0.0
Nonenergy	—	-0.15	—	—	—	—	—	—	—	-0.15
Total energy	14.20	3.18	0.44	(4.10)		3.4	3.2	0.15	0.03	28.7
percent of total	49.5%	11.1%	1.5%	14.3%		11.8%	11.2%	0.5%	0.1%	100%
Energy services										
Residential	5.23	0.12	0.07	(0.27)		3.3	3.2	0.15	0.03	12.4
Residential	18.2%	0.4%	0.2%	0.94%		11.5%	11.2%	0.5%	0.1%	43.%
Cooking	8.7%	—	0.2%	—		11.5%	10.5%	0.4%	0.1%	31.4%
Space heating	9.5%	—	—	—		—	0.7%	0.1%	—	10.3%
Lighting	—	0.4%	—	0.94%		—	—	—	—	1.3%
Commercial/public	0.31	0.27	0.00	(0.19)		—	—	—	—	0.77
Commercial/public	1.1%	0.9%	—	0.66%		—	—	—	—	2.7%
Industrial	9.41	1.77	0.37	(3.06)		0.1	—	—	—	14.7
Industrial	32.8%	6.2%	1.3%	10.7%		0.3%	—	—	—	51.3%
Process heat	32.8%	3.4%	1.3%	—		0.3%	—	—	—	37.8%
Mechanical drive	—	2.8%	—	10.7%		—	—	—	—	13.5%
Transport	0.59	0.57	0.00	(0.08)		—	—	—	—	1.24
Transport	2.1%	2.0%	—	0.28%		—	—	—	—	4.3%
Road	—	0.8%	—	—		—	—	—	—	0.8%
Rail	2.1%	—	—	0.28%		—	—	—	—	2.4%
Air	—	—	—	—		—	—	—	—	—
Other	0.00	1.2%	0.00	—		—	—	—	—	1.2%
Agriculture	0.98	0.44	—	(0.50)		—	—	—	—	1.92
Agriculture	3.4%	1.5%	—	1.7%		—	—	—	—	6.7%

— Not available or not applicable.

( ) data in parentheses is sum of nonthermal energy output and thermal energy input.

SOURCE: Adapted from International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989); and Vaclav Smil, "China's Energy," contractor report prepared for the Office of Technology Assessment, 1990.

Table 3A-3—India: Energy Supplies and Services, 1985 Exajoules (10^{18} Joules = 0.9478 Quad) and Percent of National Total

	Fossil fuels			Electricity		Biomass			
Energy supplies	Coal	Oil	Gas	Nonthermal	Thermal	Wood	Dung	Crop	Total
Production	3.16	1.29	0.17	0.20	—	0.87	1.2	1.6	8.5
Trade/stock change	0.03	0.48	—	—	0.00	—	—	—	0.5
Electric generation	-1.29	-0.11	-0.05	—	1.45	—	—	—	—
Nonenergy	—	-0.09	—	—	—	—	—	—	-0.09
Total energy	1.90	1.57	0.12	(1.65)		0.87	1.2	1.6	8.9
percent of total	21%	18%	1.3%	19%		10%	13%	18%	100%
Energy services									
Residential	0.06	0.39	0.007	(0.20)		0.78	1.2	1.6	4.2
Residential	0.7%	4.4%	0.08%	2.2%		8.8%	14%	18%	47%
Cooking/water heating	0.6%	1.9%	0.08%	—		8.8%	14%	18%	43%
Lighting	—	2.1%	—	1.8%		—	—	—	3.9%
Appliances	—	—	—	0.4%		—	—	—	0.4%
Commercial/public	0.02	0.03	—	(0.09)		0.05	—	*	0.20
Commercial/public	0.2%	0.3%	—	1.0%		0.6%	—	*	2.2%
Cooking/heating	0.2%	0.3%	—	—		0.6%	—	*	1.1%
Lighting	—	—	—	0.4%		—	—	—	0.4%
Appliances	—	—	—	0.6%		—	—	—	0.6%
Industrial	61	0.40	0.113	(0.97)		0.04	—	—	3.1
Industrial	18%	4.5%	1.3%	10.9%		0.5%	—	—	35%
Process Heat	18%	3.1%	1.3%	—		0.5%	—	—	23%
Motor Drive	—	0.8%	—	10.0%		—	—	—	10.8%
Lighting	—	—	—	0.5%		—	—	—	0.5%
Appliances	—	—	—	0.5%		—	—	—	0.5%
Transport	0.23	0.77	—	(0.04)		—	—	—	1.0
Transport	2.6%	8.7%	—	0.5%		—	—	—	11.8%
Road	—	7.1%	—	—		—	—	—	7.1%
Rail	2.6%	0.7%	—	0.5%		—	—	—	3.8%
Air	—	0.8%	—	—		—	—	—	0.8%
Agriculture[a]	—	0.15	0.003	(0.28)		—	—	—	0.43
Agriculture	—	1.7%	0.03%	3.1%		—	—	—	4.8%
Motor Drive	—	1.0%	—	3.1%		—	—	—	4.1%
Traction	—	0.7%	—	—		—	—	—	0.7%

— Not available or not applicable.

( ) data in parentheses is sum of nonthermal energy output and thermal energy input.

* Small.

[a] Baseline data from the International Energy Agency for petroleum use in agriculture have been modified to correspond better with TERI energy data.

SOURCE: Adapted from International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989); Tata Energy Research Institute, *TEDDY*, op. cit., footnote 56; and Ashok Desai, contractor report prepared for the Office of Technology Assessment and personal communication.

Table 3A-4—Kenya: Energy Supplies and Services, 1980, Petajoules (10^{15} Joules) and Percent of National Total

	Fossil fuels			Electricity		Biomass fuels		
Energy supplies	Coal	Oil	Gas	Nonthermal	Thermal	Wood[a]	Residues	Total
Production	—	—	—	3.82	—	320	9.3	333
Trade/stock change	0.42	78	—	0.44	—	—	—	79
Electric generation	—	-6.1	—	—	6.1	—	—	0.0
Nonenergy	—	-2.3	—	—	—	—	—	-2.3
Total energy	0.42	70	—	(10.4)		320	9.3	410
percent of total	0.1%	17.1%	—	2.5%		78.%	2.3%	100%
Energy services								
Residential	—	6.84	—	(2.19)		253	9.3	271
Residential	—	1.67%	—	0.53%		62%	2.3%	67%
Cooking	—	0.53%	—	0.32%		62%	2.3%	65%
Lighting	—	1.14%	—	0.21%		—	—	2%
Commercial	—	0.75	—	(1.92)		3.5	—	6.2
Commercial	—	0.18%	—	0.47%		0.85%	—	1.5%
Cooking/heating	—	0.05%	—	—		0.85%	—	0.9%
Lighting	—	0.13%	—	0.47%		—	—	0.6%
Industrial	0.42	16.5	—	(3.23)		56	—	76
Industrial	0.1%	4.0%	—	0.79%		13.6	—	18.5%
Informal	—	—	—	—		9.4%	—	9.4%
Formal	0.1%	4.0%	—	0.79%		4.2%	—	9.1%
Transport	—	43.3	—	—		—	—	43.1
Transport	—	10.6%	—	—		—	—	10.6%
Road	—	6.9%	—	—		—	—	6.9%
Rail	—	0.6%	—	—		—	—	0.6%
Air	—	2.8%	—	—		—	—	2.8%
Agriculture	—	6.6	—	(1.06)		—	—	7.7
Agriculture	—	1.6%	—	0.26%		—	—	1.9%

( ) data in parentheses is sum of nonthermal energy output and thermal energy input.

[a] Includes both commercial and noncommercial uses of wood; does not include wood used as a feedstock or as a construction material. Also includes charcoal that is produced from wood. This conversion takes roughly 110 PJ of wood and converts it into about 27 PJ of charcoal, of which about 1.3 PJ is lost during distribution.

SOURCE: Adapted from International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989); and "Energy and Development in Kenya," Eds. Phil O'Keefe, Paul Raskin, and Steve Bernow, Beijer Institute, Royal Swedish Academy of Sciences, Stockholm, Sweden, 1984.

Table 3A-5—Taiwan: Energy Supplies and Services, 1987, Petajoules (10^{15} Joules) and Percent of National Total

	Fossil fuels			Electricity		Biomass	
Energy supplies	Coal	Oil	Gas	Nonthermal	Thermal	Wood[a]	Total
Production	38.9	5.4	42.3	145	—	21	253
Trade/stock change	363	758	—	—	—	—	1121
Electric generation	-220	-58.3	—	—	278	—	0
Nonenergy	—	-46.8	—	—	—	—	-47
Total energy	182	658	42.3	(423)		21	1326
percent of total	13.7%	49.6%	3.2%	31.9%		1.6%	100.%
Energy services							
Residential	0.14	46.3	19.6	(67.5)		21	175
Residential	*%	3.5%	1.5%	6.6%		1.6%	13.2%
Cooking/water heating	—	3.5%	1.5%	0.3%		1.6%	6.9%
Lighting	—	—	—	1.0%		—	1.0%
Refrigeration	—	—	—	1.9%		—	1.9%
Television	—	—	—	1.2%		—	1.2%
Fans/air conditioning	—	—	—	1.5%		—	1.5%
Commercial/public	0.12	31.6	4.0	(47.2)		0.3	83.2
Commercial/public	*%	2.4%	0.3%	3.6%		—	6.3%
Cooking/water heating	*%	2.4%	0.3%	0.1%		*%	2.8%
Lighting	—	—	—	1.2%		—	1.2%
Air conditioning	—	—	—	1.1%		—	1.1%
Other Appliances	—	—	—	1.2%		—	1.2%
Industrial	180	314	18.5	(255)		—	767.5
Industrial	13.6%	23.7%	1.4%	19.2%		—	57.9%
Transport	—	222	—	(2.7)		—	225
Transport	—	16.7%	—	0.2%		—	17.0%
Road	—	15.0%	—	—		—	15.0%
Rail	—	0.1%	—	0.1%		—	0.2%
Air	—	1.0%	—	*		—	1.0%
Other	—	0.6%	—	*		—	0.6%
Agriculture	—	37.3	—	(13.0)		—	50.3
Agriculture	—	2.8%	—	1.0%		—	3.8%

— Not available or not applicable.

( ) data in parentheses is sum of nonthermal energy output and thermal energy input.

* Small.

[a] Charcoal is included under wood. The charcoal conversion efficiency is assumed to be a relatively high level of 50 percent by energy.

SOURCE: Adapted From International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989); and personal communication, Dr. Gwo-Tzeng, Energy Research Group and Institute of Traffic and Transportation, National Chiao Tung University, Taipei, Taiwan.

Table 3A-6—United States: Energy Supplies and Services, 1985,[a] Exajoules (10^{18} Joules = 0.9478 Quad) and Percent of National Total

	Fossil fuels			Electricity		Biomass[b]	
Energy supplies	Coal	Oil	Gas	Nonthermal	Thermal	Wood[a]	Total
Production	19.6	20.9	16.5	2.53[c]	—	2.80	62.3
Trade/stock change	-1.8	8.9	1.2	0.06[d]	—	—	8.4
Electric generation	-14.8	-1.1	-3.0	—	18.9	-0.02	—
Nonenergy	—	-1.8	—	—	—	—	-1.8
Total energy	3.0	26.9	14.7	(21.5)		2.8	68.9
percent of total	4.4%	39%	21.3%	31.2%		4.1%	100%
Energy services							
Residential	0.1	1.5	5.3	(7.6)		1.0	15.5
Residential	0.1%	2.2%	7.7%	11.%		1.5%	22.5%
Space conditioning	—	2.0%	5.3%	4.3%		1.5%	13.1%
Water heating	—	0.2%	1.8%	1.5%		—	3.5%
Cooking	—	—	0.5%	0.7%		—	1.2%
Refrig/Freezers	—	—	—	1.6%		—	1.6%
Lighting/Other[e]	—	—	0.1%	2.8%		—	2.9%
Commercial/public	0.1	1.2	2.9	(6.6)		—	10.8
Commercial/public	0.2%	1.7%	4.2%	9.6%		—	15.7%
Space conditioning	—	1.6%	2.9%	6.1%		—	10.6%
Water heating	—	0.1%	0.1%	0.1%		—	0.3%
Lighting	—	—	—	2.5%		—	2.5%
Industrial	2.6	4.3	6.5	(7.3)		1.8	22.5
Industrial	3.8%	6.2%	9.4%	10.6%		2.6%	32.7%
Heat[f]	3.8%	(11.8%)[g]	—	1.2%		2.6%	19.4%
Motor Drive	—	—	—	7.1%		—	7.1%
Off-Highway transport	0.9%	—	—	—		—	0.9%
Transport	—	19.3	—	(0.03)		—	19.3
Transport	—	28.%	—	*%		—	28.%
Road	—	23.1%	—	—		—	23.1%
Rail	—	0.7%	—	*%		—	0.7%
Air	—	3.9%	—	—		—	3.9%
Other	—	0.3%	—	—		—	0.3%
Agriculture[h]	—	0.6	—	—		—	0.6
Agriculture	—	0.9%	—	—		—	0.9%

— Not available or not applicable.

( ) data in parentheses is sum of nonthermal energy output and thermal energy input.

* Small.

[a] Note that the IEA data used as a framework for this energy balance differs slightly from official U.S. energy statistics. See, for example, Energy Information Administration, *Monthly Energy Review*, January 1990.

[b] Split 58 percent Nuclear and 42 percent Hydroelectric and other (geothermal, solar, etc.).

[c] Imports of electricity into the United States are primarily hydroelectric based power from Canada.

[e] Includes clothes washers and dryers, dishwashers, lighting, and miscellaneous.

[f] Includes fuels used for cogeneration applications.

[g] Oil and gas applications are combined here.

[h] This does not include indirect inputs (fertilizer, etc.).

SOURCE: Adapted from International Energy Agency, *World Energy Statistics and Balances: 1971-87* (Paris: OECD, 1989); and Paul D. Holtberg, Thomas J. Woods, Marie L. Lihn and Nancy C. McCabe, *Baseline Projection Data Book: 1989 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010* (Washington, DC: Gas Research Institute, 1990).

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Appendix 3-B—Sources for Table 3-9

As used here, efficiency is approximately the first-law efficiency; that is, the total heat transfer to the material being processed divided by the heat input to the system. This is to be contrasted with the second-law efficiency, which compares the heat transfer achieved in the process with the maximum possible heat that could be transferred for the same purpose by any system using the same energy input. For more information, see *Efficient Use of Energy*, AIP Conference Proceedings, No. 25, American Institute of Physics, New York, 1975.

Cooking: The primary source for traditional and modern cooking technologies is Samuel F. Baldwin, *Biomass Stoves: Engineering Design, Development, and Dissemination*, op. cit., footnote 17. An enormous range of efficiencies have been reported for the open fire, ranging from 2 to 30 percent. A list of some 45 reports on traditional cooking technology efficiencies was developed by Jas Gill in 1981 and is cited in K. Krishna Prasad, *Woodburning Stoves: Their Technology, Economics, and Deployment* (Geneva: 1983). International Labor Organization, World Employment Programme Research. Most of these reports, however, do not cite a source, nor any details as to how such an efficiency figure was derived.

Traditional Beer Brewing: Data are from Frans Sulilatu, "Improved Beer Cookers In Burkina Faso," *Boiling Point*, No. 10, pp. 10-14, August 1986. This is the thermal efficiency of heating the brew to boiling, not for the entire brewing process. In Burkina Faso, West Africa, traditional dolo (beer) cookers using 80-liter clay jars have thermal efficiencies of 17 percent with a power output of 80 kW for a cooker with four jars arranged in a square, and 15 percent at 35 kW with the jars arranged in a line with fires between adjacent jars. Simple improvements in stove design and the use of aluminum pots raised efficiencies up to as high as 53 percent.

The efficiency of the brewing process can also be determined by calculating the total amount of useful energy provided. Mnzava, cited below, has estimated that 0.12 to 0.5 m^3 of fuelwood are needed to brew 100 liters. Assuming that 1 m^3 of stacked fuelwood weighs 500 kg and has an energy content of 16 MJ/kg for a total of 8 GJ; and assuming that the energy is used to bring the water to a boil once to sterilize it and then to maintain its temperature at a low level while it ferments; the energy required to heat 100 liters of water to a boil from ambient (20 °C) is 100(80)4.186 = 14 MJ. This gives an efficiency range of 0.3 to 0.7 percent for the beer-brewing process. This very low efficiency compared to the thermal efficiency found for dolo cookers in Burkina Faso may be due to the long, low temperature heating needed to concentrate the mash as well as for other operations. See: E.M. Mnzava, "Fuelwood and Charcoal In Africa," W. Palz, P. Chartier, and D.O. Hall (eds.), *Energy From Biomass*, 1st E.C. Conference on Biomass, Brighton, East Sussex (London: Applied Science Publishers, Ltd., 1980).

Modern Beer Brewing: Data are from Bernard B. Hamel et al., "Energy Analysis of 108 Industrial Processes," 1980. The figure of 79 percent is the overall boiler efficiency for a modern brewery. This boiler provides process steam, hot water, and other heating services. The efficiency of the cooking process is somewhat reduced from this level, but no separate estimate was available.

The value of 6 percent is based on a total energy demand for a brewery found by Hamel et al., of 1,439 Btu per pound of beer produced or, equivalently, 3.35 MJ/kg compared to the energy required to heat the brew to boiling a single time to sterilize it—as in the comparison made for the traditional technology.

Tobacco Drying: The estimate of tobacco drying efficiency is from M.J. Mwandosya and M.L. Luhanga, *Energy Use Patterns In Tanzania*, Center for Energy and Environmental Studies, Princeton University, Report No. 180, February 1985; and M.J. Mwandosya and M.L. Luhanga, "Energy Demand Structures in Rural Tanzania," Department of Electrical Engineering, University of Dar-es-Salaam, Tanzania, 1984.

Traditional Tea Drying: Tea drying is based on the data in Mwandosya and Luhanga, listed above. They estimate that 150 kg. of green tea requires 9.4 GJ of fuelwood, resulting in 30 kg. of dried tea. To evaporate 120 kg of water requires 2,260(120)kJ = 271 MJ of energy, for an efficiency of 2.9 percent.

Traditional Baking: For traditional bakeries, Ahmed and Elamgzoub found 0.5 to 0.8 kg of wood used per kg of flour. Typical ratios for bread are 720 g flour, 500 g liquid, and 50 g sugar input per kg of bread output. With specific heats of 1.8 kJ/kg °C for flour, 4.186 kJ/kg °C for water, and arbitrarily assuming 4.0 kJ/kg °C for sugar; and noting that approximately half the water evaporates, the rest remaining in the bread (Geller); then the energy required to bake 1 kg of flour into bread at 190 °C is: (1.0)(1.8)(170) + (0.7)(4.186)(80) + (0.35)(2260) + (0.35)(4.186)(90) + (0.09)(4.0)(170) = 1.5 MJ, where it was assumed that the specific heat of the water remaining in the bread, 0.35 kg, remained 4.186 and the chemical reactions and heating of the vaporized steam were ignored. By comparison, 0.5 to 0.8 kg wood have an energy content of 8 to 13 MJ. Abdel Salaam Ahmed and El Sheikh Elamgzoub, *Survey of Fuelwood Consumption in Khartoum Province Industries* (Khartoum, Sudan: National Energy Administration, Ministry of Energy and Mining for the Energy Research Council, Sudan Renewable Energy Project, April 1985. Howard S. Geller and

Gautam S. Dutt, "Measuring Cooking Fuel Economy", *Wood Fuel Surveys* (Rome: 1983). Food and Agriculture Organization of the United Nations, GCP/INT/365/SWE.

Reddy and Reddy found that 0.583 kg wood were used to cook 1 kg of maida, corresponding to an efficiency of 16 percent. Amulya Kumar N. Reddy and B. Sudhakar Reddy, "Energy Use in a Stratified Society: Case Study of Firewood in Bangalore," *Economic and Political Weekly (India)*, vol. 18, No. 41, Oct. 8, 1983.

Shirey and Selker list the efficiencies of a number of traditional and modern ovens used in a variety of countries. Ovens in Somalia, Sudan, Guatemala, Zimbabwe, and Sri Lanka have typical measured efficiencies of 1 to 3 kg wood per kg flour, giving efficiencies, as calculated above, of 3 to 8 percent. In contrast, an improved wood-fired Somali oven is cited as using 0.16 kg of wood to cook 1 kg of flour into bread—an efficiency of 58 percent; and modern natural gas ovens are listed as baking 360 kg of flour into bread using 1 GJ of energy —an efficiency of 54 percent. E. Shirey and J. Selker, "Bread Ovens," *Boiling Point*, No. 10, pp. 18-21, 1986.

Modern Bakeries: Ho, Wijeysundera, and Chou found first-law efficiencies for a modern industrial bakery in Singapore to be 43 percent for the entire process, including preparation of the dough. Second-law efficiencies were also calculated and found to be 15.5 percent. J.C. Ho, N.E. Wijeysundera, and S.K. Chou, "Energy Analysis Applied to Food Processing," *Energy* vol. 11, No. 9, 1986, pp. 887-892.

Fish Smoking: Mwalyosi estimates that smoking 1 kg of fresh fish requires 4 to 5 kg dry wood. If 70 percent of the fish is assumed to be water, then it requires (2,260 kJ/kg)(0.7 kg) = 1.6 MJ to evaporate the water compared to (4 to 5 kg)(16 MJ/kg) = 64 to 80 MJ of wood to accomplish the task, for an efficiency of 2.0 to 2.5 percent. Raphael B. Mwalyosi, "Management of the Mtera Reservoir in Tanzania," *AMBIO*, vol. 15, No. 1, 1986, pp. 30-33.

Traditional Brick Firing: Schmitt estimates 1.36 MJ of energy is required per kg of brick produced in order to evaporate moisture from the raw brick (after drying in the sun) and heat it to a firing temperature of 850 °C, and an additional 0.2 to 0.4 MJ/kg is needed for the chemical reactions. Based on observations at six sites, an average of 2.5 MJ fuelwood and other organic matter were used per kg of brick produced, for an efficiency of (0.2 to 0.4)/2.5 = 8 to 16 percent. It should be noted that these results were for very large kilns, firing typically 100,000 bricks at a time. Klaus Schmitt and Werner Siemers, *Energy From Agricultural Residues and Energy Utilization In Small Scale Industries In The Sudan*, Section 5.4, "Brick Kilns" (Gottingen, Sweden: for the National Energy Administration of Sudan, Khartoum, September 1985).

Gandhi found an efficiency of 6.4 percent for brick kilns in India, representing the irreversible reactions that take place during firing. The overall heat balance found by Gandhi for a Bull's trench was: energy in = 3.88 MJ + 0.29 MJ in carbon in brick; energy out is 61.4 percent in dry exhaust; 16.9 percent in moisture in exhaust; 6.4 percent in irreversible reactions; 4.0 percent in heat loss of CO; 0.3 percent in carbon in ash; and other heat losses (by difference) of 11 percent—presumably, much of this loss was through the kiln walls. Other types of kilns require from 2 to 18 MJ/brick for firing. With an average brick size of 108 in3 or 108(16.387) cm3 and an average brick density of 1,800 kg/m3, this gives an energy requirement of 2 to 18 MJ/3.18 kg or 0.637 to 5.7 MJ/kg. Sunita Gandhi, "The Brick Industry in India: Energy Use, Tradition and Development," Ph.D. Thesis, Trinity College, Cambridge, October 1986.

The brick and tile industry in Uganda uses 0.5 to 1.8 stacked cubic meters of wood per metric ton of brick produced; with 7,650 MJ/m^3 for eucalyptus at 510 kg/stacked m^3 to give, at best, 3,800 MJ per metric ton of brick output. Potential energy savings of 35 percent may be possible simply with better firing techniques and kiln construction, and by the introduction of small cavities and organic materials into the brick to reduce mass and improve the uniformity of firing. Using the figures for Sudan, this gives an efficiency of about 5 to 10 percent when assuming the chemical reactions need 0.2 to 0.4 MJ/kg; using the figures for India this gives an efficiency of about 2 percent. "Uganda: Energy Efficiency Improvement in the Brick and Tile Industry," World Bank/UNDP Energy Sector Management Assistance Program, March 1989.

Modern Brick Industry: Assuming the same range as for Sudan, that irreversible chemical reactions for the process are 0.2 to 0.4 MJ/kg of fired brick, a modern brick factory has an efficiency of 6-11%. The relatively high observed efficiency of the traditional process relative to modern kilns is largely due to substantial underfiring in traditional kilns and corresponding low-quality product. Calculated from Bernard B. Hamel et al. "Energy Analysis of 108 Industrial Processes," op. cit.

Traditional Foundry Work: In Indonesia, an estimated 1 kg of charcoal is used per kg of aluminum melted and cast into pots. From the *CRC Handbook of Chemistry and Physics*, the melting point of aluminum is 933 °K and its specific heat varies linearly with temperature from C_p=0.9 kJ/kg °C at 300 °K to 1.19 kJ/kg °C at 933 °K. The energy needed to heat it to its melting point is then given by MC_pDT=658 kJ/kg. To melt the aluminum requires an additional 398 kJ/kg (CRC Handbook). The total process then requires 1,056 kJ/kg. Charcoal has a calorific value of about 33 MJ/kg. The process is therefore about 3 percent efficient. World Bank, *Indonesia: Issues and Options in the Energy Sector*, UNDP/World Bank Energy Sector Assessment Program Report No. 3543-IND, November 1981.

Modern Foundry work: Figure of 40 percent is from Bernard B. Hamel et al., "Energy Analysis of 108 Industrial Processes," op. cit. above, p. 282.

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Chapter 4

Energy Supplies in the Developing World

Introduction and Summary

This chapter provides an overview of the energy *supply* sector in the developing world—the processes and technologies by which energy is produced, converted from one form into another, and delivered to users. The energy supply sector is critical for economic development for two reasons: first, economic growth depends on the availability of reliable sources of energy; and second, the energy supply sector absorbs a large share of investment—over 40 percent of the total public investment in some developing countries,[1] and about 15 percent of foreign assistance.[2] The energy supply sector also relies heavily on other resources that can be scarce in the developing world, including skilled labor and management, water, and land.

The energy supply sector is critical to economic development. Economic growth depends on the availability of reliable sources of energy, and the energy supply sector absorbs a large share of public and foreign aid investment.

The developing countries use a wide range of energy sources. Coal is the largest primary energy source in developing countries, due mainly to the coal-based energy sectors of China and India, the two largest energy consumers in the developing world. Excluding China and India, oil and electricity are the mainstays of commercial energy supplies in developing countries. In rural and poor urban areas, traditional biomass fuels are the primary energy source.

Although the developing world as a whole is a net oil exporter, the exports originate from a relatively small number of countries. Most of the countries in the developing world depend heavily on imported oil, and these imports consume a large fraction of export earnings.

The commercial energy supply system—coal, oil and gas, and electricity—requires large amounts of foreign exchange, skilled labor, and trained management. It is characterized by state ownership, in contrast to supplies of traditional fuels, which are largely in private hands.

Commercial energy supplies in many countries are unreliable and of poor quality due to operational inefficiencies, rapid increases in energy demand, problems of reaching dispersed populations served by inadequate transport systems, and inappropriate pricing and allocation systems.

Operational efficiencies in the energy industry are somewhat lower in many developing countries than in the industrial countries. This record of "poor" performance often reflects the older equipment and difficult conditions under which energy facilities operate. The existence of such differences between operational efficiencies in reasonably standardized operations suggests that improvements are possible if some of these obstacles can be overcome.

Generalizations about energy supplies in developing countries obscure the heterogeneity of the developing world. Performance standards vary considerably between countries, as do prospects for expanding energy supplies in the future.

The Overall Primary Fuel Mix

According to the International Energy Agency (IEA), coal supplied 35 percent of the developing world's primary energy[3] in 1987 (table 4-1 and figure 4-1), followed by oil (31 percent), biomass fuels (19 percent), primary electricity (mostly hydropower) (8 percent), and natural gas (7 percent). Some analysts believe instead that biomass is in fact the largest source of energy, supplying up to one-third of primary energy in the developing world.

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[1] M. Munasinghe, *Electric Power Economics* (London: Butterworths, 1990).

[2] World Bank, *Annual Report 1989* (Washington, DC: 1989). Data include only International Development Authority (IDA) and International Bank for Reconstruction and Development (IBRD) lending in fiscal year 1989.

[3] "Primary energy" refers to fuels in their raw state, before they are processed into forms suitable for use by final consumers. Primary fuels include coal, oil, gas, biomass, and electricity generated from nuclear, hydro, geothermal, and solar sources. "Final energy," suitable for end-use consumption, includes electricity generated from fossil fuels as well as primary electricity. For countries with fossil fuel electricity generation facilities, the amount of electricity in the final energy mix is therefore higher than in the primary energy mix, and the amounts of fossil fuels are lower by the amounts used to generate electricity. Electricity generated from fossil fuels is not included in primary energy in order to avoid double counting.

Table 4-1—Energy Supply Mix, 1987 (percent)

Fuel	China	India	Brazil	Rest of developing world	Total developing world	United States
Coal	70	38	6	17	35	24
Oil	17	22	38	41	31	41
Natural gas	2	3	2	12	7	22
Other[a]	4	5	26	8	8	9
Biomass fuels[b]	7	33	28	22	19	4
Total (percent)	100	100	100	100	100	100
Total (exajoules)	26.7	9.6	6.9	42.0	85.2	77.9

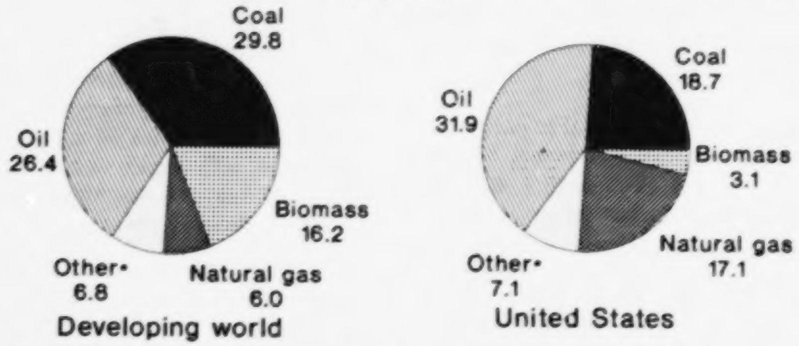
[a] Includes hydropower, nuclear, geothermal, solar, and electricity produced from biomass. Converted at heat equivalent.

[b] Note that these estimates for the share of energy supplied by biomass are lower than that indicated by detailed field surveys. See, for example, figure 3-1 and app. 3-A.

NOTE: Total may not add to 100 percent due to rounding.

SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989); IEA, *Energy Balances of OECD Countries 1987-1988* (Paris: OECD, 1990).

Figure 4-1—Energy Supply Mix in the Developing World and in the United States, 1987 (exajoules)



•Includes hydropower, geothermal, other renewables, and nuclear converted at heat equivalent. Biomass numbers may be underestimates, see text, and alternative source, figure 1-2.

SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989); IEA, *Energy Balances of OECD Countries 1987-1988* (Paris: OECD, 1990).

The relative shares of these energy sources in the overall energy supply mix vary significantly across different regions and countries, due in part to unequal endowments of energy resources. Coal supplies about half of the energy requirements for developing countries in Asia, due largely to high levels of coal consumption in China and India[4] (table 4-1 and figure 4-2). Oil is the major source of commercial primary energy for most countries of the developing world, India and China being the notable exceptions. Natural gas supplies a relatively small fraction of energy in the developing world, although in countries with well-developed resources, gas often represents an important source of energy (in Mexico, for example, natural gas supplies 20 percent of the primary energy consumed).[5] Biomass fuels are a significant energy source throughout the developing world, particularly in rural areas and in the poorest countries.

Overall, the developing world produces more energy than it consumes, and significant amounts of both oil and gas are exported from developing countries (figure 4-3). There are, however, major disparities among countries: only a few developing countries export energy, and most import over 50 percent of the commercial energy they consume.

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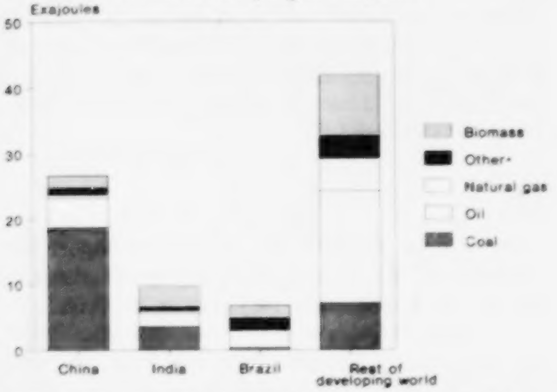
[4] International Energy Agency (IEA), *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989), using 1987 data. This includes IEA estimates for biomass consumption, and converts electricity to energy units at the heat equivalent.

[5] Ibid.

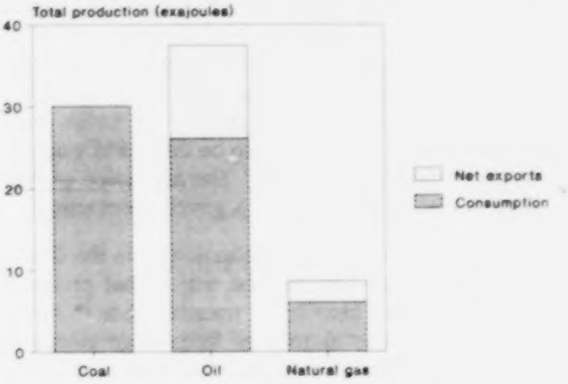
Figure 4-2—Energy Supply Mix for Selected Regions of the Developing World, 1987



*Includes hydropower, geothermal, other renewables, and nuclear converted at best equivalent. Biomass numbers may be underestimates, see text.

SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989).

Figure 4-3—Primary Energy Production, Consumption, and Exports in the Developing World, 1985



SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989).

Coal

Coal production and consumption in the developing world are concentrated in a relatively small number of countries. China, India, South Africa, South Korea, and North Korea are responsible for 96 percent of the total coal production in the developing world. China alone accounts for 65 percent of developing world coal production and 27 percent of world coal production.[6]

The largest consumer of coal in the developing world is industry, which accounts for over 40 percent of total developing world coal use.[7] The bulk of the industrial coal use is in China. Other significant coal-consuming sectors are electric utilities, transportation (coal-burning locomotives), and the residential sector in China, where coal is used for cooking and space heating.

Rates of coal production[8] are growing rapidly. Hard coal production in Asia grew at an average annual rate of 5.7 percent from 1980 to 1987, and lignite production grew at 8.9 percent during the same period.[9] This growth is expected to continue.

Coal quality in the less developed world varies widely, both within and among countries.[10] In India and China, most coal has a relatively low sulfur content but a high ash content.[11] There are few washing and sorting processes at coal mines, so the quality of coal supplies is unpredictable. In China, for example, less than one-fifth of all coal mined is cleaned before combustion. The rest is used raw, limiting the efficiency of combustion.

The coal industry accounts for about 16 percent of total commercial energy investment requirements in low-income developing countries.[12] In India and China, the largest coal users, domestic sources finance most of this investment.

Government-owned entities are responsible for most coal mining, transport, and distribution in developing countries. In China, the Ministry of Coal

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[6] Ibid., p. 59, 1987 production of hard coal only.

[7] Ibid., 1985 data. The United States, in contrast, uses most of its coal for electricity generation.

[8] As shown in figure 4-3, net coal exports are insignificant, so for the developing world as a whole coal production is the same as coal consumption. Some individual developing countries do trade in coal—e.g., South Africa is a coal exporter and the Republic of Korea is a coal importer.

[9] IEA, op. cit., footnote 4.

[10] The important attributes of coal quality are energy density (typically measured in Joules per kilogram or Btu per pound), sulfur content, and ash content.

[11] Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook 1988* (New Delhi, India: 1989); Vaclav Smil, "China's Energy," contractor report prepared for the Office of Technology Assessment, 1990.

[12] World Bank, *The Energy Transition in Developing Countries* (Washington, DC: 1983), p. 68. For period 1982-92.

Industry controls about 600 of China's 20,000 mines, grouped under 84 Coal Mine Administrations or Coal Industry Companies. The remaining, mostly smaller mines are run through local governments at the provincial, county, or prefecture level, or as collective township and village enterprises. In India, the government-owned Coal India Corp. accounts for 87 percent of production. Coal India, with 675,000 employees, claims to be the world's largest single corporate employer.[13] The allocation of supplies is also in the hands of a government entity.

Although coal mining technologies in the developing world are diverse, the major coal producer —China—relies heavily on manual labor.[14] About two-thirds of the extraction from large mines in China depends on manual labor, as does virtually all production from locally run mines and small private pits. Not surprisingly, labor productivities are very low, averaging less than 1 ton per miner per shift. This rate is significantly lower than current U.S. rates, which average about 10 tons per miner per shift.[15]

Although China has considerable experience with a wide variety of advanced underground mining techniques and has the ability to produce most of the machinery required, the country does not have sufficient capital or technical expertise to modernize its coal industry completely. However, surface extraction methods, which can be less expensive, are being used at many newly developed sites. Five large pits are now under development in China with a total initial capacity of 50 million tons per year. The largest of these should eventually produce up to 60 million tons per year.

Transportation requirements often limit coal production. In China, coal accounts for 40 percent of all freight movement, most of which is by rail. China's already overloaded transport system is struggling to keep up with its growing coal production. Incomplete and poorly configured networks, backups at mode transfer points, and breakdowns all contribute to the unreliability of the coal transport system. As a result, coal-using industries must stockpile up to a year's supply, or turn to other fuels. Similar problems occur in India.[16]

Oil

Petroleum products are easy to transport and versatile in use in all sectors and at all scales of operation; consequently, they play an important role in the energy sectors of developing countries. These attributes led to an average annual growth rate of 4.5 percent for oil consumption in the developing world from 1971 through 1987.[17] Oil consumption is expected to continue rising by about 3 percent per year, thereby doubling between 1985 and 2010.[18]

More than one-third of the oil consumed in the developing world is used for transportation (figure 4-4 and table 4-2). The share of oil used for transportation varies from 13 percent in China to 42 percent in Latin America—considerably lower than the 62 percent share in the United States. The developing world, compared to the United States, uses proportionally more oil for electricity generation and for industry. The entire developing world consumes about 25 percent less oil than the United States alone.

The bulk of developing world oil production is concentrated in a few countries—14 developing countries account for over 90 percent of developing world oil production.[19] Although the developing world as a whole is a net oil exporter, the exports originate from a relatively small number of countries.[20] Most developing countries depend heavily on oil imports. More than half of the low- and lower middle-income countries import 90 percent or more

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[13] IDEA, Inc., "Clean Coal Technologies for Developing Countries," contractor report prepared for the Office of Technology Assessment, May 1990.

[14] This discussion is drawn from Vaclav Smil, "China's Energy," op. cit., footnote 11.

[15] Relative to the United States, labor is cheaper and mechanization is more expensive—so one would expect greater use of labor inputs and less mechanization in China than in the United States.

[16] For example, one textile mill in India is converting from coal to rice husks as a boiler fuel because of the extreme unreliability of coal supplies (V. Kothari, consultant, Isotem Services, New Delhi, India, personal communication, April 1990).

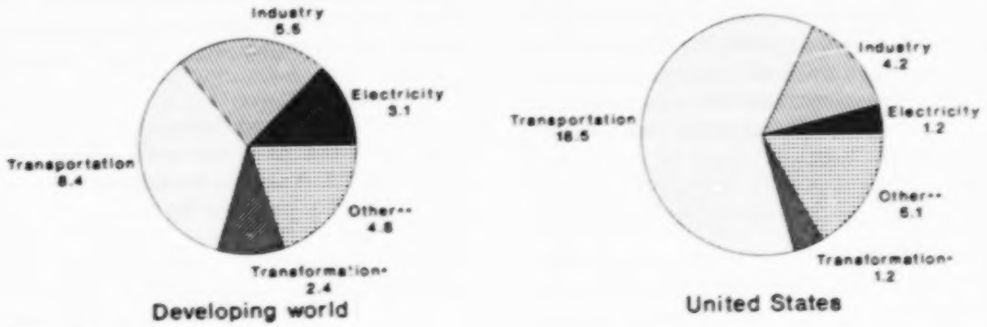
[17] IEA, op. cit., footnote 4.

[18] Alan S. Manne and Leo Schrattenholzer, *International Energy Workshop: Overview of Poll Responses* (Palo Alto, CA: Stanford University, July 1989) International Energy Project.

[19] These are, in order of decreasing oil production, Mexico, China, Venezuela, Indonesia, Nigeria, Algeria, Libya, Egypt, Brazil, India, Malaysia, Argentina, Colombia, and Angola. IEA, op. cit., footnote 4.

[20] Five countries—Mexico, Nigeria, Venezuela, Libya, and Indonesia—account for over 60 percent of LDC oil exports. IEA, op. cit., footnote 4.

Figure 4-4—Oil Consumption by End Use in the Developing World and in the United States, 1985 (exajoules)



*Refinery use and losses.
**Residential, agricultural, and nonenergy.

SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989) IEA, *Energy Balances of OECD Countries 1970/1985* (Paris: OECD, 1987).

Table 4-2—Oil Consumption by End-Use Sector, 1985 (percent)

Sector	Asia[a]	China	Africa	Latin America	Total developing world	United States
Electricity	12	15	13	12	13	4
Transformation[b]	10	10	5	10	10	4
Industry	24	40	18	16	23	14
Transportation	35	13	41	42	35	62
Other[c]	16	19	17	16	16	11
Nonenergy[d]	3	4	6	4	4	6
Total (percent)	100	100	100	100	100	100
Total (exajoules)	7.5	3.9	3.5	9.1	24.0	29.9

[a] Excluding China.
[b] Transformation includes losses, refinery use, and statistical differences.
[c] Other is largely residential and agriculture.
[d] Non-energy use includes waxes, asphalt, and lubricants.
NOTE: Totals may not add to 100 percent due to rounding.

SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989); IEA, *Energy Balances of OECD Countries 1970/1985* (Paris: OECD, 1987).

of their commercial energy; almost all of the imports are in the form of oil (see app. 1A). By comparison, the United States imports about 17 percent (net) of its energy, of which 90 percent is in the form of oil or oil products.[21] The continued expansion of oil consumption imposes an economic burden on developing countries, either in the form of foreign exchange for imported oil or for investment in oil exploration and development. Investment in the oil supply infrastructure is comparable with that in the electricity sector, each accounting for about 40 percent of total commercial energy investment in the developing world.[22]

In most developing countries, natural resources such as oil and gas are considered state property. Ownership or other economic rights to these natural resources are not bought and sold with the surface rights (as in the United States), but are reserved for the state to exploit or to contract out to third parties. In most oil-exporting developing countries, supreme authority over oil and gas is legally vested in a central government entity—(e.g., the Ministry of Oil in Egypt or the Ministry of Petroleum and Minerals in Oman), which delegates sectoral oversight and operational responsibility to a national oil company (e.g., the Egyptian General Petroleum Corp.). In practice, however, there are wide disparities among different countries in the actual relationships among executive power, sectoral ministries, and national operating entities. In oil-exporting countries, such as Argentina and Algeria, the national operating companies have more power than the ministries they depend on, due to the companies' autonomous sources of revenue from significant oil production. In contrast, in oil-importing countries, such as Sudan, the national oil companies have little power.

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[21] Energy Information Administration (EIA), *Monthly Energy Review December 1989*, DOE/EIA-0035(89/12) (Washington, DC: U.S. Government Printing Office, February 1990).

[22] World Bank, op. cit., footnote 12, p. 68.

Only the wealthier oil-exporting developing countries invest much of their own money in exploration and development. All the poorer ones, and the majority of the others, rely on the international oil industry for most of the required capital and technical expertise. The "enabling mechanism" under which foreign oil companies invest in developing countries varies widely from country to country, but certain aspects are widespread. Generally, the ministry in charge of the sector authorizes the national oil company to negotiate exploration rights with foreign companies. This negotiation may require the formation of a formal joint venture with the national company. More typically, however, a loose relationship is formed in which the two associates remain entirely separate, with the foreign party providing all the capital and most of the technical control of operations. Once a deal is concluded, it is ratified at the central government level.

The fiscal arrangements made under these enabling mechanisms have in the past been inflexible, providing for the same overall rate of government take on all sizes of fields. These arrangements are satisfactory for the middle range of expected reserves and costs. When oil fields are larger than expected, however, the government fails to capture a reasonable share of the profits on the petroleum being produced. When fields turn out smaller then expected—a typical occurrence in many developing countries—the government share precludes economic development by the foreign operator. This discourages the development of small fields. A further discouragement to foreign oil companies for the development of oil fields for domestic consumption rather than export is uncertainty over the availability of foreign exchange for the remittance of profits.

Despite these disadvantages, U.S. oil companies in recent years have increased their investments outside North America, particularly in developing countries. The prospect of adding to corporate reserves at half the cost of domestic exploration[23] apparently more than compensates for the uncertainty of foreign investment.

Refineries and Distribution

Although the world's oil refining capacity is concentrated in the industrialized countries, many of the developing countries, including oil-importing countries, have considerable domestic refining capacity. Over half of the countries in Africa have refineries,[24] many of which are hydroskimmers (see box 4-A). In the developing world, refineries are usually owned by the government, which acts through a national oil company, although foreign companies sometimes manage and operate the refineries.

The refinery product mix in developing countries differs significantly from that in the United States, due in part to the inflexibility of the hydroskimming technology. In developing countries, between 60 and 70 percent of refinery output is diesel and residual, compared with 30 percent in the United States. On the other hand, gasoline accounts for about half of U.S. production, compared with about 20 percent in developing countries.[25] In general, refineries in developing countries have higher production costs than those in the industrialized world: average refinery operating costs in Africa are $2 per barrel, compared to $0.75 per barrel in the rest of the world.[26] Refineries in the developing world also suffer from large losses due to the use of old, inefficient technology, as well as poor maintenance. Refinery losses, which should not exceed 1 percent

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[23] The cost of finding a barrel of oil in the United States is $6, compared with $3 in the rest of the world (Salomon Brothers Inc., *Proved Petroleum Reserves of 30 Large Energy Companies 1980-87* (New York, NY: 1988), p. 14.

[24] United Nations, *1986 Energy Statistics Yearbook* (New York, NY: 1988).

[25] Ibid.

[26] T. Gorton, "Oil and Gas Development in Third World Countries," draft contractor report prepared for the Office of Technology Assessment, April 1990.

Box 4-A—Refinery Technology

Crude oil is a mixture of hydrocarbons. In the simplest refining process, primary distillation (also known as hydroskimming), crude oil is simply heated. This causes the lightest hydrocarbons, such as gasoline and liquid petroleum gas, to boil off first. As the temperature increases, different products (such as kerosene and diesel oil) boil off. The residual, known as residual fuel oil, remains. This relatively simple process does not allow for much flexibility in the mix of yielded products. For example, 18 to 23 percent gasoline and 30 to 55 percent residual fuel oil are typical yields from primary distillation.[1]

Secondary conversion, which includes fluid catalytic cracking (FCC) and hydrocracking, uses high temperatures to "crack" large molecules into smaller ones. This process allows for greater flexibility in product mix, and is often used to increase the proportions of lighter hydrocarbons, such as gasoline and LPG, while reducing the proportion of residual fuel oil. For example, hydrocracking allows for up to 86 percent (by weight) gasoline production, compared with 18 to 23 percent for primary distillation.[2] However, secondary cracking is relatively expensive and complex.

[1] L. Wijetilleke and A. Ody, "World Refinery Industry—The Need for Restructuring," World Bank Technical Paper No. 32, Washington DC, 1984, p. 32a.

[2] Ibid., p. 33a.

in a properly maintained and operated refinery, often exceed 2 or even 4 percent in developing countries.[27]

During the 1970's and 1980's, both the structure and the level of petroleum product prices changed. As the prices of petroleum products increased, coal, gas, and hydroelectricity were substituted for residual fuel oil in electricity generation, leading to a relative decrease in the demand for residual fuel oil. When the gap between gasoline and diesel prices widened (due to diesel subsidies and/or gasoline taxes), consumers switched to diesel cars. As a result, the structure of demand for petroleum products changed in many countries; the demand for the middle distillates increased relative to the demand for gasoline at the top end and residual fuel at the bottom. Developing country refineries, which typically do not have secondary conversion technology, could not adjust to these changes. As a result, some of their surplus petroleum products had to be exported, often at distress prices, while other products had to be imported.[28]

Because of these developments in the international petroleum market, several developing countries are producing refined petroleum products at costs higher than those prevailing on the international market. Up until recently, for example, Liberia had only one refinery, which was poorly maintained, inefficient, and in need of upgrading. An economic analysis of this refinery showed that importing the refined petroleum products directly and shutting down the inefficient domestic refinery would result in net savings of $15 million to $20 million per year (U.S. dollars), equivalent to a gain of about 2 percent in Liberia's gross domestic product (GDP).[29] Several other African countries are in similar situations.

The distribution system for petroleum products plays a key role in determining whether or not the economy has sufficient and dependable fuel supplies. Because large portions of the population are scattered in rural areas, and transport infrastructures are frequently inadequate, the distribution systems in developing countries are often unreliable. In addition, price controls, supply monopolies, rationing systems, and requirements for uniform pricing in all areas may further limit the dependability of petroleum in developing countries.

Natural Gas

Natural gas plays a relatively minor role in the energy supply system in most developing countries, supplying only 7 percent of total energy use in the developing world (see table 4-1). This contrasts sharply with its role in the industrialized world. In the United States, for example, natural gas supplies 22 percent of domestic energy consumption. However, gas is an important source of energy for a small number of developing countries. Five countries—Mexico, Argentina, Venezuela, China, and Algeria—

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[27] Refinery losses result from leakage, evaporation, and spills; they are distinct from "own use" consumption, which is oil intentionally consumed in the refinery process for heat, transport, and drive. See T. Gorton, op. cit., footnote 26.

[28] L. Wijetilleke and A. Ody, "World Refinery Industry—The Need for Restructuring," World Bank Technical Paper No. 32, Washington, DC, 1984.

[29] T. Wilbanks and S. Wright, "Energy for Development: ORNL Returnsto the Third World," *ORNL Review*, No. 3, 1988.

account for 58 percent of developing world natural gas consumption. Natural gas consumption in the developing world is concentrated in industry, where it is used both as a fuel and as a feedstock. Natural gas is also used for electricity generation.

Discovered gas reserves in many developing countries are not developed. The current production levels from developed reserves are only 16 percent of the level that current proven reserves could sustain.[30] Thus, many developing countries import large quantities of crude or fuel oil while possessing reserves of natural gas that could serve more economically and with less harm to the environment.[31]

The reasons for the relative underutilization of natural gas in the developing world lie more in institutional than in technical or financial constraints. Although gas is associated with oil exploration and development and therefore shares many of the same problems, it has additional difficulties of its own. In the exploration phase, due to the fiscal or contractual terms under which gas is discovered, gas discoveries are often treated as "dry holes" by oil exploration companies.[32] In the development phase, gas requires heavy front-end capital investments (pipelines from producing to consuming regions, or, in the case of overseas trade, costly facilities and tankers to liquefy and transport the gas) and long-term agreements between suppliers and consumers. And the high cost of building distribution systems in cities deters the development of domestic markets for natural gas.

The specific requirements of gas development are particularly difficult for developing countries, where financing for large capital-intensive projects is hard to find, and where the main purchaser for the gas is the state. When the developer is a private foreign corporation, the problems are complicated by uncertainty that sufficient foreign exchange will be available for the investor to repatriate profits. This last difficulty is especially acute in the case of highly indebted developing countries where the bulk of scarce hard currency is earmarked in advance for payments on debt. Unlike the electricity sector, which shares many of these characteristics, development of natural gas reserves has generally not been financed by donor agencies.

Biomass Fuels

Biomass fuels are an important source of energy in the developing countries, supplying over three-fourths of the total energy consumed in almost all of the lower income developing countries.[33] The contribution of biomass fuels to total energy supplies in the entire developing world is unclear. Biomass fuel consumption is difficult to measure, as much of it never enters a commercial market. As shown in table 4-1, biomass fuels supply about 19 percent of total energy according to the International Energy Agency. Other researchers, however, estimate this number at 33 to 35 percent.[34]

Biomass fuels are the dominant energy source in rural areas, and they are also widely used in poorer urban areas, as well as in some large-scale industrial processes. These "traditional fuels" consist of wood (firewood and charcoal), dung (from cattle and other animals), and crop wastes (e.g., wheat, rice straw, and sugar cane bagasse). Wood is the most widely used and preferred fuel due to its superior combustion characteristics. Its share of total biomass energy supply varies widely among the developing countries, according to region and agricultural and forestry resource base. In many regions of Africa and Latin America (with the important exception of Brazil, where bagasse is also used), wood is the primary form of biomass energy used. In Asian countries, wood remains the dominant biomass fuel (accounting for one-half of all biomass consumed in

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[30] World Bank, op. cit., footnote 12, p. 36.

[31] To mention just the sub-Saharan African countries with undeveloped gas fields: Mozambique, Ethiopia, Somalia, Madagascar, Cote d'Ivoire, Equatorial Guinea, Sudan, Senegal, Tanzania, and Namibia.

[32] By one estimate, about half of the natural gas produced in the developing world is flared or otherwise wasted. The comparable number for Eastern Europe is 2 percent. A. Mashayekhi, "Natural Gas Supply and Demand in Less Developed Countries," *Annual Review of Energy*, vol. 13, 1988, pp. 119-129.

[33] The role of biomass fuels in the total energy supply varies greatly among countries, showing generally an inverse relationship with GNP per capita. For example, Ethiopia (GNP per capita = $U.S. 130) meets 92 percent of its energy needs with biomass fuels, while Argentina (GNP per capita = $U.S. 2,390) meets only 7 percent of its needs with biomass fuels.

[34] K. Smith, "The Biofuel Transition," *Pacific and Asian Journal of Energy*, 1987, pp. 13-32; P. O'Keefe, J. Soussan, B. Munslow, and D. Spence, "Wood Energy in Eastern and Southern Africa," *Annual Review of Energy*, vol. 14, 1989, pp. 445-468.

China, and three-quarters in India), but crop wastes and animal dung also play a significant role.[35]

Biomass Resource Base

For a variety of reasons, the fuelwood supply base is shrinking rapidly. This could have serious impacts on the populations that depend on forests for fuel, food, fiber, fodder, and other needs.

The total global annual growth of forest biomass is subject to great uncertainty, but has been estimated to be about 50 times annual wood consumption or five times total annual energy consumption, including fossil fuels. Despite this apparently large average global supply, there are acute and growing shortages of fuelwood both locally and regionally. Some regions, such as Asia, have very little forest stock per capita (table 4-3). Within regions, some countries are well endowed with biomass energy resources, while others have totally inadequate supplies; and within countries themselves, local abundances and shortages are common. Zaire, for example, consumes only 2 percent of its sustainable yield of forest biomass but has serious deforestation around Kinshasa.[36]

Despite the uncertainties regarding rates of biomass energy use and supply, it is clear that the populations affected by fuelwood shortages are increasing. The United Nations Food and Agriculture Organization (UNFAO) has estimated that the number of people suffering acute shortages of fuelwood will increase from about 100 million in 1980 to over 350 million in the year 2000. Such shortages increase fuel costs for urban dwellers, lengthen the time spent foraging for fuel by rural dwellers, and rob the soil of nutrients as people switch from wood to crop wastes and dung (although the impact of this nutrient loss may be limited except in the much longer term).

Rural Biomass Markets

Much of the biomass fuel supply in developing countries—especially twigs, branches, dung, and crop wastes—is gathered locally and used by family members without entering commercialized markets.

Table 4-3—Biomass Energy Resources in Selected Developing Countries

	Sustainable energy yield (GJ per capita per year)		
Country	Wood	Crop residues	Animal dung
Congo	570	1	—
Brazil	350	8	16
Zaire	135	1	1
Argentina	123	25	40
Thailand	37	9	4
Nepal	21	7	13
Burkina Faso	10	5	7
India	7	5	6
Bangladesh	2	4	5
China	—	7	3

— data not available or not applicable

SOURCES: G. Barnard and L. Kristoferson, *Agricultural Residues as Fuel in the Third World* (London: Earthscan, 1985); D. Hall, G. Barnard, and P. Moss, *Biomass for Energy in the Developing Countries*, Pergamon Press, 1982. R. Moss and W. Morgan, *Fuelwood and Rural Energy Production and Supply in the Humid Tropics*, (Dublin, Ireland: Tycooly International Publishing Ltd, 1981).

These supplies are gathered free of charge (if the considerable cost of the labor used in gathering is not included) from fields, hedgerows, gardens, and nearby forest lands. In some cases, however, the poor may have to "pay" with labor services for the privilege of gathering biomass fuels from privately owned land.

Commercial Biomass Markets

Biomass fuels, notably logs and charcoal, are also traded in commercial markets far from their origin in government and private forests, farms, or plantations. Low-income urban households and small commercial enterprises use the bulk of these fuels. In some cases, however, biomass fuels are used for advanced industrial applications, as in the case of charcoal for iron smelting in Brazil. In such cases, the industrial users often organize the biomass fuel supplies.

Unlike other forms of energy, supplies of commercialized biomass fuels are largely in the hands of the private sector. Much of the fuelwood may be grown on privately owned land,[37] and the transport and distribution channels for commercialized biomass fuels are typically in private hands, as are charcoal kilns.[38]

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[35] Crop wastes account for one-half of total traditional energy supply in China and just over 10 percent in India. Animal dung accounts for about 20 percent of traditional fuel use in India, Pakistan, and Bangladesh but under 2 percent in China.

[36] R. Moss and W. Morgan, *Fuelwood and Rural Energy Production and Supply in the Humid Tropics* (Dublin, Ireland: Tycooly International Publishing Ltd., 1981).

[37] In several Indian cities, for example, government lands were found to provide less than 10 percent of total fuelwood supplies (M. Alam, J. Dunkerley, and A. Reddy, "Fuelwood Use in the Cities of the Developing World: Two Case Studies From India," *Natural Resources Forum*, vol. 9, No. 3, 1985).

On the other hand, the fuelwood trade is often subject to government regulation, with strict rules about cutting trees in government forests and even on private lands. Although it is believed that such regulations are not strictly enforced, often because of the difficulty of enforcement, proscriptions against cutting trees can discourage the development of long-term supplies, as farmers and others are unwilling to invest in tree planting for fuelwood if they have no assurance that they can harvest the trees at maturity. Fuelwood prices may also be subject to price controls (in Senegal, for example, charcoal prices are controlled by the government). And in some cases, governments may play a role in the distribution system as well. Compared with commercial fuels, however, the biomass trade is relatively unregulated.

The transport of wood and charcoal to urban areas is carried out in a variety of ways. In India, poor women carry head loads of fuel to urban markets; in Niger, camels carry fuel into the capital city of Niamey; and elsewhere fuel is carried by bicycle, animal cart, moped, and other means. In higher income areas, trucks or trains carry the bulk of the fuel.

Charcoal

In rural areas, the cutting of fuelwood and its conversion to charcoal is a major source of income and nonagricultural employment. Charcoal is made by stacking the wood, covering it with a layer of dirt, and letting it burn with a limited supply of air. The efficiency of converting wood to charcoal in these simple earthen kilns is quite low, typically ranging from 40 to 60 percent.[39] If a capital investment is made, ranging from a few hundred dollars for simple modifications to traditional kilns[40] to $100,000 or more for a modern continuous retort, higher energy efficiencies can be achieved.

Although it is widely believed that charcoal is cheaper to transport than wood due to its higher energy content by weight, detailed studies have found that the transportation costs for wood and charcoal are about the same.[41] The higher energy content of charcoal per unit weight is counterbalanced by its lower weight per unit volume.

Despite its higher price, charcoal is widely used in some countries, particularly in urban areas where people have cash incomes. A 1970 report from Thailand, for example, indicated that 90 percent of the wood cut for urban markets was converted to charcoal.[42] It has several important advantages over wood. Charcoal is impervious to insect attack, unlike some wood species that must be used within as little as a month of drying to avoid significant losses to termites.[43] As it is nearly smokeless, charcoal cooking can be done indoors in relative comfort without blackening walls or metal pots with soot. In addition, charcoal causes little smoke irritation to eyes or lungs. Although it can emit large amounts of dangerous carbon monoxide and other pollutants, which is a health hazard in poorly ventilated kitchens, charcoal causes little obvious discomfort to the user. Additionally, once lit, charcoal fires need little attention from the cook, whereas wood fires require frequent adjusting of the fuel.

Biomass Pricing

When people move from rural to urban areas in developing countries, they typically continue to follow traditional patterns of biomass fuel use. In contrast to the labor-intensive collection of biomass fuels in rural areas, however, the urban poor often have no choice but to purchase fuelwood or charcoal in commercial markets. In Tanzania, the cost of purchasing these fuels reportedly ranges as high as

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[38] M. Alam, J. Dunkerley, and A. Reddy, Ibid.

[39] *Charcoal Production Improvement for Rural Development in Thailand* (Bangkok, Thailand: Royal Thai Government and U.S. Agency for International Development, 1984); D. Earl, *Charcoal Production, Sudan Renewable Energy Project*, Energy Research Council, USAID, Report No. 002, Khartoum, Sudan, February 1984; J. Wartluft and S. White, *Comparing Simple Charcoal Production Technologies for the Caribbean* (Arlington, VA: Volunteers in Technical Assistance, 1984).

[40] K. Christophersen, G. Karch, and J. Seve, "Production and Transportation of Fuelwood and Charcoal From Wood Surplus to Deficit Regions in Niger: Technical and Economic Feasibility" (Washington, DC: Energy/Development International, March 1988).

[41] T. Wood and S. Baldwin, "Fuelwood and Charcoal Use in Developing Countries," *Annual Review of Energy*, vol. 10, 1985, pp. 407-429.

[42] J. Arnold, "Wood Energy and Rural Communities," *Natural Resources Forum*, vol. 3, 1979, pp. 229-252.

[43] Simon Nkonoki and Bent Sorensen, "A Natural Energy Study in Tanzania: The Case of Bundilya Village," *Natural Resource Forum*, vol. 8, No. 1, 1984, pp. 51-62.

40 percent of the income of poor families.[44] More typically, energy accounts for 5 to 10 percent of the expenditures of poor households.[45]

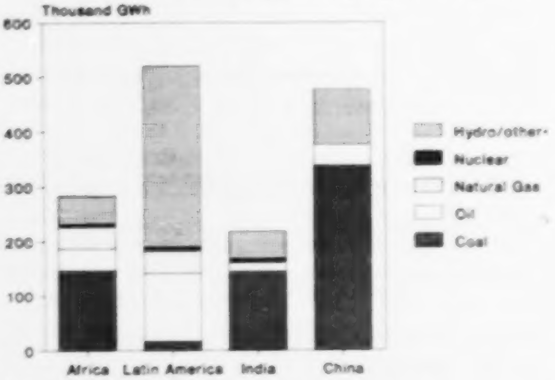
Biomass fuel prices in urban markets often rise rapidly as wood resources are seriously depleted, and then closely follow fossil fuel markets. Biomass costs cannot rise very far above the cost of an equivalent amount of useful energy from kerosene or LPG, as users can and will then switch fuels.[46] Families that purchase modern stoves and fuels, however, rarely discard the older stoves. Maintaining both technologies allows easy and flexible switching between fuels in response to availability and price. Following the 1973 and 1979 oil price increases, for example, many people switched back to wood and charcoal for their cooking needs. In Malawi the use of kerosene, primarily for cooking and lighting, declined by 24 percent between 1973 and 1976.[47]

Electricity

Electrification plays a central role in promoting economic and social development in any nation. At the same time, the electricity sector consumes large amounts of economic, social, and environmental resources. Accordingly, the electric power sector receives significant attention and resources from both developing country governments and international development agencies. For example, the World Bank directs over 80 percent of its energy lending to the electricity sector.

Although electricity accounts for less than 9 percent of the energy used by consumers in developing countries,[48] electricity production in the developing world is increasing rapidly, at an average annual rate of 7.6 percent.[49] However, this rapid growth still leaves the developing world at a far lower level of electricity production than the industrialized world: average annual electricity production in the developing world is about 520 kilowatt-hours (kWh) per capita,[50] as compared with the U.S. figure of 10,500 kWh per capita.[51]

Figure 4-5—Electricity Generation by Fuel Type in Selected Regions of the Developing World, 1987



*Includes hydropower, geothermal, and other renewables.

SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989).

Electricity Generation

In the developing world, as in the United States, a variety of fuels and technologies are used for electricity generation (see figure 4-5 and table 4-4).

Coal use for electricity production in the developing world is concentrated, largely in countries with sizable domestic coal reserves (India, China, and South Africa). Similarly, natural gas generating capacity is found mainly in the few countries where natural gas is produced domestically. In other countries, oil is often used for electricity generation.

Hydroelectric facilities range from microhydropower stations with less than 0.1 megawatt (MW) of capacity to large-scale hydropower plants such as the 12,600 MW Itaipu facility in Brazil. For countries with hydroelectric potential, hydropower offers an indigenous source of electricity generation with very low operating costs, although the capital costs

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[44] E.M. Mnzava, "Village Industries vs. Savannah Forests," *UNASYLVA*, vol. 33, No. 131, 1981, pp. 24-29.

[45] Gerald Leach and Marcia Gowen, "Household Energy Handbook," World Bank Technical Paper No. 67, 1987, p. 50.

[46] Douglas F. Barnes, "Understanding Fuelwood Prices in Developing Nations," World Bank, Household Energy Unit, Industry and Energy Department, Oct. 31, 1989.

[47] J. Arnold, "Wood Energy and Rural Communities," *Natural Resources Forum*, vol. 3, 1979, pp. 229-252.

[48] IEA, op. cit., footnote 4, pp. 112, 120, 124, 128.

[49] For the period 1971-87. IEA, op. cit., footnote 4.

[50] U.S. Agency for International Development, *Power Shortages in Developing Countries: Magnitude, Impacts, Solutions and the Role of the Private Sector* (Washington, DC: Office of Energy, U.S. AID, March 1988), p. 2.

[51] Energy Information Administration, *Annual Energy Review*, DOE/EIA-0384(88) (Washington, DC: U.S. Government Printing Office, 1989).

Table 4-4—Electricity Generation by Fuel, 1987 (percent by kWh delivered)

Fuel	Africa	Latin America	China	India	United States
Coal	52	3	68	66	57
Oil	14	24	12	8	5
Natural gas	14	8	*	1	11
Nuclear	3	1	0	2	18
Hydro/other[a]	18	63	20	23	10
Total (percent)	100	100	100	100	100
Total (GWh)	283,340	520,290	497,320	217,500	2,732,530

*Less than 1%.

[a] Includes hydropower, geothermal, and other renewables.

NOTE: Does not include heat losses. Totals may not add to 100 percent due to rounding.

SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989); IEA, *Energy Balances of OECD Countries 1987-1988* (Paris: OECD, 1990).

are high. In Latin America, hydropower plays a large role, supplying almost two-thirds of total electricity.[52] More than 90 percent of Brazil's total electricity supply comes from hydropower.[53] In Africa, almost half of the electricity generated outside of South Africa comes from hydropower,[54] and more than two-thirds of the countries in Africa produce electricity from hydroelectric plants.[55]

Only eight developing countries were generating electricity from nuclear powerplants as of late 1989,[56] although several more have plants planned or under construction.[57] Nuclear power generation involves high capital costs, very large scales of operation, and considerable technical expertise. In two upper income developing countries, Taiwan and Korea, nuclear power provides over 40 percent of total electricity generation. In other countries, however, there have been some difficulties with nuclear power—e.g., two of India's three operating nuclear plants have suffered high outage rates,[58] and their fourth plant has had construction delays of 7 years.

A number of alternative generation technologies have also been used in developing countries, including cogeneration, geothermal, conversion of solar energy to electricity, wind-driven generators, and the burning of waste material. Although these sources contribute relatively small amounts to total electricity supplies in the developing world, there is strong policy interest in expanding the use of these alternative generating technologies.

The operating efficiencies of electricity generating plants are generally lower in developing countries than in the United States.[59] Although many factors affect power plant efficiency (notably input fuel quality), the use of less efficient, poorly maintained technologies contributes to the low efficiencies of developing world powerplants.

Electricity Transmission and Distribution

Transmission and distribution systems in the developing world have relatively high losses. A recent survey of 76 developing countries found that, in one-half of the countries surveyed, transmission and distribution losses (as a share of total generation) exceeded 15 percent, compared with typical losses of less than 10 percent in the industrialized countries.[60] These losses include both technical losses and unmetered consumption (theft).

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[52] IEA, op. cit., footnote 4.

[53] Ibid.

[54] United Nations, op. cit., footnote 24.

[55] Ibid.

[56] These are Argentina, Brazil, India, Mexico, Pakistan, Republic of Korea, South Africa, and Taiwan. United Nations, "Energy Exploration and Development Trends in Developing Countries," Report of the Secretary-General, May 14, 1990.

[57] Argentina, Brazil, China, Cuba, Mexico, India, and Republic of Korea all had nuclear powerplants under construction in 1989. Ibid.

[58] Tata Energy Research Institute, op. cit., footnote 11.

[59] United Nations Conference on Trade and Development (UNCTAD), *Technology Policy in the Energy Sector: Issues, Scope and Options for Developing Countries*, UNCTAD/TT/90, June 15, 1989.

[60] Ibid.

Institutional Issues

Governments in both the developing and industrialized world generally have taken leading roles in directing the development and operation of the electric power sector; this reflects both the importance of electric power in meeting economic and social objectives and the high cost of electric power systems.

Because electricity is considered an important tool within a broader national development strategy,[61] developing countries often subsidize electricity prices. In Pakistan, for example, 60 percent of the cost of electricity is subsidized; in India, the figure is 20 percent.[62] Many countries have subsidies for electricity in selected sectors (e.g., agriculture and residential), reflecting either the political influence of the subsidized sectors or government interest in promoting certain economic or social ends. Although electricity prices nearly doubled between 1980-81 and 1986-87 in India, for example, current prices are still far lower than supply costs for residential and agricultural consumers.[63]

There may be many reasons for subsidizing electricity prices in different sectors. For example, rural electrification is promoted as a means to reduce migration to cities by improving economic opportunities and lifestyles in rural areas. Supporters argue that these subsidies benefit society as a whole and not just rural consumers. Others argue that there is no conclusive evidence that rural electrification can actually produce this benefit.[64] Rural electrification is also seen as "a powerful instrument at the disposal of central governments to foster political stability in rural areas," although again the evidence is mixed.[65]

Subsidized electricity prices also allow electricity to compete with subsidized prices for alternative fuels. Similarly, when prices of farm products are controlled and kept artificially low, electricity prices (and the prices of other inputs such as fertilizers) are often subsidized to keep farms operating.[66]

Subsidized electricity can have negative impacts, including contributing to power shortages, since consumers tend to use more subsidized electricity than they would otherwise. Moreover, price subsidies keep power company revenues at levels inadequate for developing additional supplies and even for maintaining existing facilities efficiently. Higher prices, on the other hand, limit supplies to higher income groups, an outcome that may conflict with the social goals of electrification.

Capital spending on electricity systems in the developing world is currently estimated at $50 billion to $60 billion annually.[67] Even at that high level of expenditure, investment is expected to be inadequate to meet demand. The United States Agency for International Development (U.S. AID) has estimated that meeting the growing demand for electricity will require capital investment of around $125 billion per year over the next two decades.[68] This enormous capital mobilization requirement represents a large fraction of both total economic activity and total gross domestic investment in the developing world. The total economic output of all lower- and middle-income countries as measured by GDP was $2,716 billion in 1987, with total gross domestic investment of $662 billion.[69] Much of the capital costs of electricity plants must be paid in foreign exchange,[70] leading to balance of payment problems and compounding the problems of high operating and capital costs in the electric sector.

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[61] United Nations Center for Human Settlements (Habitat), *Guidelines for the Planning of Rural Settlements and Infrastructure: Electrification—A Methodology* (Nairobi, Kenya: United Nations, 1985), p. 43.

[62] U.S. Agency for International Development, op. cit., footnote 50, p. 26.

[63] A. Faraqui et al., *Application of Demand-Side Management (DSM) to Relieve Electricity Shortages in India*, draft contractor report prepared for the Office of Technology Assessment, April 1990, p. 59.

[64] For a discussion of these issues, see D. Barnes, *Electric Power for Rural Growth* (Boulder, CO: Westview Press, 1987), pp. 109-118.

[65] United Nations Center for Human Settlements (Habitat), op. cit., footnote 61.

[66] Mohan Munasinghe, *Rural Electrification for Development* (Boulder, CO: Westview Press, 1987), p. 247.

[67] U.S. Agency for International Development, op. cit., footnote 50, p. iv.

[68] Ibid., p. 25. A slightly lower estimate ($60 to $100 billion) from the World Bank is given in A. Churchill and R. Saunders, "Financing of the Energy Sector in Developing Countries," World Bank, Industry and Energy Department Working Paper Energy Series, Paper No. 14, April 1989.

[69] World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), tables 3 and 9.

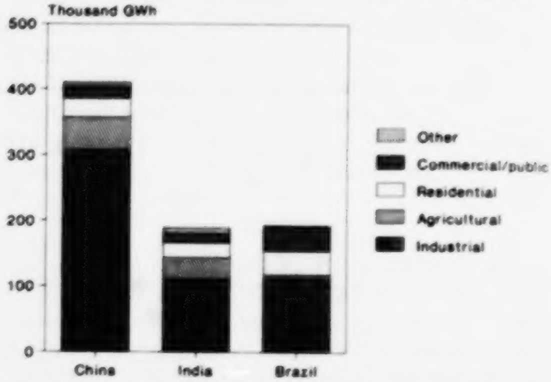
[70] U.S. AID estimates that around 45 percent of capital investment will be in foreign exchange. U.S. Agency for International Development, footnote 50, p. 25.

Even with the enormous financial, technical, and institutional effort targeted to the development of the electricity sector over the past decades, capacity still is often insufficient to provide reliable, high-quality power in developing countries. Outages are common in many countries. For example, Bombay experienced 1,000 outages annually over a recent 5-year period.[71] Even when power is available, voltage fluctuations are often extreme, restricting the use of some types of equipment. The electronic circuits of today's compact fluorescent light bulbs, for example, do not tolerate wide voltage fluctuations;[72] and computer operations are disrupted by outages. As a result, in many countries, poor power quality and lack of reliability undermine the economic benefits of electric power.

Low reliability results in formidable losses in economic productivity. Load shedding in India is estimated to cost the equivalent of 1 to 3 percent of GDP annually.[73] Accurately estimating the productivity lost when existing equipment cannot be operated due to power outages is difficult, and estimating productivity lost as industry forgoes the purchase and use of new electric equipment is even more uncertain; however, the impacts may be quite large.

Ironically, a few developing countries suffer from an *excess* of electric capacity. For example, it has been estimated that seven East African countries have approximately 7,000 MW of excess generating capacity (i.e., capacity over and above what is needed for reliable system operation).[74] This situation results from the "lumpiness" of electric generating facilities, especially hydropower. Putting a large new generating facility in service before the domestic load can absorb the new supplies results in overcapacity, and ties up scarce capital.[75]

Figure 4-6—Electricity Consumption by Sector in Selected Regions of the Developing World, 1985



SOURCE: International Energy Agency, *World Energy Statistics and Balances 1971-1987* (Paris: OECD, 1989).

Electricity Consumption

Industry consumes most of the developing world's electricity (see figure 4-6 and table 4-5). In contrast, electricity use in the United States is divided among the industrial, residential, and public service/commercial sectors (see table 4-5). China, the largest electricity user in the developing world,[76] uses 75 percent of its electricity in industry. Similarly, India and Brazil use over half their electricity in industry. Agriculture uses large amounts of electricity for pumping in India and China, while residential lighting and appliances use large amounts of electricity in Brazil.

Outlook for Improvements

The mix of energy supplies varies widely in the developing world—from China's heavy reliance on coal in the industrial and residential sectors to Brazil's extensive use of hydropower-based electricity. Despite the diversity of sources, however,

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[71] Tata Energy Research Institute, *Two Strategies for Electric Load Leveling for India*, Phase I Final Report (New Delhi, India: 1987), p. 6., as cited in J VanDomelen, *Power to Spare: The World Bank and Electricity Conservation* (Washington, DC: World Wildlife Fund and Conservation Foundation, 1988) p. 4.

[72] Lawrence Berkeley Laboratory, *Energy Technology for Developing Countries: Issues for the U.S. National Energy Strategy*, LBL-28907 (Berkeley, CA: December 1989).

[73] U.S. Agency for International Development, op. cit., footnote 50, p. 21.

[74] I. Hume, "Energy Efficiency in Developing Countries," in M. Munasinghe and R. Saunders (eds.), *Energy Issues in the Developing World*, World Bank Industry and Energy Department Working Paper, Energy Series Paper No. 1 (Washington, DC: World Bank, 1988).

[75] Excess capacity can also lead to distortions in pricing and demand. For example, the large surplus capacity in Brazil when Itaipu came on-line led the electricity authorities to offer industry exceptionally strong incentives to buy electricity. Electricity was so cheap that it was used by industrial customers virtually as a boiler fuel. Within a few years, however, load growth in other sectors reduced surplus capacity, but the industrial users were by then reluctant to give up the highly favorable rates.

[76] Over one-fourth of the electricity in the developing world is used in China.

Table 4-5—Electricity Consumption by Sector, 1985 (percent)

End-use sector	China	India	Brazil	United States
Industry	75	59	58	33
Agriculture	12	17	3	1
Residential	7	12	20	35
Public service/commercial	5	8	20	31
Railroads	2	2	1	*
Other/unspecified	*	1	*	0
Total (percent)	100	100	100	100
Total generation (GWh)	410,700	188,500	192,700	2,621,900

*Less than 1 percent.

NOTES: Totals may not add to 100 percent due to rounding. Brazil, China, and India account for 48 percent of developing world electricity consumption.

SOURCES: Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook 1988* (New Delhi, India: 1989); IEA, *World Energy Statistics and Balances 1970/1985* (Paris: OECD, 1987); IEA, *Energy Balances of OECD Countries 1987-1988* (Paris: OECD, 1990).

several important characteristics of the energy supply sector can be identified:

- The technologies in use are typically older, less efficient, and less sophisticated than comparable technologies in the industrialized countries.
- The electricity sector accounts for a large share of foreign exchange resources. Rapid growth in electricity demand and the high capital requirements of the sector suggest that the gap between needed and available capital for electricity system expansion will widen. Therefore the electricity systems in many countries could continue to be relatively undependable, inefficient, and technologically outdated.
- The public sector plays a dominant role in most aspects of energy supply, with the exception of biomass.

These characteristics of the energy supply sector in the developing world suggest a number of productive opportunities for improving the efficiency of the energy supply system, recognizing that there are wide variations among developing countries, and that many characteristics that appear inefficient or undesirable when viewed from the current perspective of highly developed nations may in fact represent rational choices given prevailing social, economic, and technical conditions.

A number of institutional, technological, and engineering options can be considered for improving the extraction, processing, and conversion of energy supplies. In oil and gas development, for example, options include both the deployment of new technologies, such as horizontal drilling, and the development of innovative financing mechanisms. Options for coal include technologies such as washing and screening, as well as strategies for minemouth electricity generation to relieve pressure on transport systems. Similarly, institutional issues are critical in any discussion of improving the sustainability of biomass resources.

Both developing country governments and international development agencies already pay much attention to opportunities in the electricity sector. Technological opportunities range from industrial cogeneration, to upgrades of transmission and distribution system efficiencies, to the use of more efficient consumer appliances. Institutional opportunities include the contribution of nonutility generators to electricity networks.

Although technology can do much to improve the energy supply sector, other factors also affect its operation: financial issues, such as subsidies for electricity prices or the high cost of natural gas transportation; institutional and management issues, including shortages of trained personnel; and the incentive structure, notably the dominant role played by government in fossil fuel exploration and delivery systems, all strongly influence system operations, management, and decisionmaking in the energy supply sector.

Chapter 5

Energy and the Environment in Developing Countries

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Chapter 5

Energy and the Environment in Developing Countries

Introduction and Summary

Many developing countries are experiencing significant environmental degradation. In rural areas, population pressure and low agricultural productivities are among the factors forcing people into marginal and ecologically fragile lands. Woodlands are being cleared for cropland and pastures and are being commercially logged. The use of biomass for fuel or fodder places further demands on woodlands and grasslands, particularly in arid regions with high population densities. Farming, ranching, logging, and the use of biomass fuels are all necessary if the people dependent on these resources are to survive. But these various pressures can also have negative impacts: destruction of tropical forests and biodiversity; desertification; soil erosion and increased downstream flooding and siltation; and air pollution—local, regional, and global.

In many urban areas of developing countries, rapid population growth, inadequate infrastructure, and economic and industrial growth with minimal or inadequately enforced environmental controls have led to high levels of pollution. Levels of sulfur dioxide, particulates, ground-level ozone, and nitrogen oxides often exceed those in industrialized countries. Major sources include electricity generation, transportation, and industrial production. Greater use of fossil fuels in the modern, primarily urban, sector can also lead to environmental degradation and pollution in the rural areas where these fuels are extracted from the ground and transported to the cities, and where hydroelectric facilities are sited.

Many have viewed environmental costs—degradation and pollution of the natural resource base—as the price that must be paid in order to develop economically.[1] Increasingly, however, others argue that environmental protection and economic development are tightly interconnected and mutually supportive.[2] The landless peasants who migrate to fragile watersheds in order to feed their families, for example, clear land that is highly susceptible to erosion. This can lead to serious soil loss and downstream flooding and siltation—ultimately reducing the productivity of their land as well as that of land downstream. In turn, this can exacerbate their and others' poverty. This may be particularly significant in developing countries because their economies are so heavily dependent on agriculture. For the 2.8 billion people in the lowest income countries, agriculture accounted for fully 31 percent of gross domestic product (GDP) in 1987 and an even greater portion of employment.[3] Economic analyses that include environmental impacts are improving knowledge of this interdependency and may assist policymakers in more wisely making these tradeoffs.

Energy production and use contribute to environmental degradation in developing countries. Other contributing factors include population growth, inequitable land tenure, unsustainable agricultural and forestry practices, industrialization, and government policies. In order to understand the role of energy in overall environmental degradation, it is therefore necessary to include these other factors in the analysis.

Energy, used wisely, might also potentially provide several important environmental benefits in developing countries. Greater energy inputs into agriculture in the form of tractive power, fertilizer, and irrigation, for example, can substantially improve agricultural productivities where soils and climates are appropriate, and might help slow the expansion of agricultural lands necessary to feed a burgeoning population. (At the same time, however, modern agriculture might also cause environmental damage: by overuse of pesticides, herbicides, and fertilizers; by waterlogging and salinizing irrigated

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[1] Clem Tisdell, "Sustainable Development: Differing Perspectives of Ecologists and Economists, and Relevance to LDCs," *World Development*, vol. 16, No. 3, 1968, pp. 373-384.

[2] World Commission on Environment and Development, *Our Common Future* (New York, NY: Oxford University Press, 1987).

[3] World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), indicator tables 1 and 3.

Table 5-1—Causes and Consequences of Environmental Degradation in Rural Areas

Consequences	Direct cause	Underlying cause
Deforestation Loss of biodiversity Soil erosion Flooding	Shifting agriculture Permanent agriculture Permanent pasture	Population growth Poverty Lack of land tenure Low-level agriculture inputs Mechanization of agriculture and/or the consolidation of agricultural lands
	Commercial logging	Destructive logging, lack of forest management and protection, poor reforestation Increased access to forests along logging roads for farmers and ranchers
	Commercial agriculture, ranching	Production for export markets Fiscal policies and legislation, in part to promote exports of primary products due to need for foreign exchange to service debt. Inappropriate economic valuations of natural resources and biodiversity
	Use of Biomass Fuels	Inefficient use of fuelwood; overcutting of fuelwood resources
	Use of forest biomass for fodder	Shortages and lack of alternative sources of fodder
Desertification	Agricultural expansion onto fragile lands Overgrazing Burning of grasslands	Population growth Poverty Lack of land tenure Low-level agriculture and/or the consolidation of agriculture lands
	Use of biomass fuels	Inefficient use of fuelwood; overcutting of fuelwood resources
	Climate change	Various; not well understood
Air pollution	Use of biomass fuels Slash and burn agriculture Burning of grasslands	Lack of access to higher quality fuels and stoves Population growth Poverty Lack of land tenure Low-level agricultural inputs
Salinization and water-logging of irrigated lands	Poor planning and management Inadequate investment in infrastructure	Cheap or free water contributing to inefficiency

SOURCE: Office of Technology Assessment, 1990.

lands; and by use of these techniques under inappropriate soil and climatic conditions).[4]

Energy-efficient technologies may offer the potential of simultaneously reducing the total cost of delivering energy services and cutting pollution. New industrial processes may increase productivity and lower costs while reducing hazardous wastes. Much research and development work remains to be done to bring many of these innovations to fruition. A later report from this OTA study will examine the extent to which improved technologies for energy production and use can contribute to economic development and environmental protection; under what circumstances energy technology innovations might ease the difficult tradeoffs between economic growth and the environment; and policy issues associated with accelerating the introduction of improved energy technologies that minimize environmental degradation.

This chapter traces the causes and consequences of environmental degradation in developing countries, beginning in rural areas and following them through to urban areas, modern industry, and the use of fossil fuels. This organization has several advantages over the more conventional cataloging of environmental problems by their impacts on land, water, and air. First, it helps capture the dynamic causes of environmental degradation in developing countries in the various contexts of the rural struggle for survival by the landless peasant, or of the urban effort to develop modern industry in an economy that has limited capital, technology, and skilled human resources. Second, it highlights the differences in the causes and consequences of environmental degradation between rural and urban areas. Third, it helps illustrate some of the complex linkages between these environmental problems that make effective responses so difficult. If economic needs are to be met while simultaneously maintaining environmental quality, these dynamics and complex interconnections must be understood and responded to appropriately.

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[4] U.S. Congress, Office of Technology Assessment, *Enhancing Agriculture in Africa: A Role for U.S. Development Assistance*, OTA-F-356 (Washington, DC: U.S. Government Printing Office, September 1988). Some note, however, that even steep or acid-infertile lands can be productive over long periods as shown by the centuries of terraced rice farming in Asia or continuous sugar-cane cropping in the Dominican Republic. See Ricardo Radulovich, "A View on Tropical Deforestation," *Nature*, vol. 346, July 19, 1990, p. 214.

The Rural Sector

Many developing countries are suffering significant environmental degradation in rural areas, including: rapid devegetation/deforestation and the loss of irreplaceable biodiversity; desertification; erosion of crop and pasture land; watershed degradation, siltation of downstream waterways, downstream flooding, and other impacts on water quality and supplies; and local and regional air pollution. In turn, these environmental impacts may damage or destroy farm and range land and force more people into watersheds and other ecologically fragile lands—potentially creating a vicious cycle of degradation. Clearing and burning woodlands and grasslands for agriculture or pasture also contribute to the global increase in atmospheric greenhouse gases.

The principal direct causes of these forms of environmental degradation are shifting cultivation, conversion of forest lands to permanent pasture and agriculture, commercial logging, overgrazing, inappropriate management of irrigated land, and the use of biomass for fuel. These factors are often interconnected. Commercial logging of closed tropical forests, for example, opens new areas with roads and partial clearings, which enables settlers to follow, converting forests to pasture and cropland.

Underlying these causes are factors such as: population growth; poverty; the lack of access to modern energy-intensive inputs for agriculture (mechanical traction, irrigation, fertilizers, etc.); the lack of secure land tenure for many people; and government pricing, tax, and other policies that may encourage misuse of natural resources. These causes and consequences are listed in table 5-1.

The extent and rate of environmental degradation are difficult to quantify accurately under the best of circumstances, even when reliable data are available. As it is, estimates vary widely on the basis of the underlying definitions of what constitutes ecological vulnerability or degradation; the methodologies used for the analysis; and the assumptions used to go from local measures of degradation to global extrapolations.

The depiction of environmental degradation also depends on what measure is used for comparison. Local degradation may be severe and rapid. Irrespective of the hardship this places on people in the immediate region and the need for local responses, it does not necessarily translate into corresponding problems at the regional or global scale. There is considerable variation in form and degree of environmental degradation from one region to another. Consequently, an attempt is made below to place estimates of the rate of local environmental degradation into the global context.

Causes of Environmental Degradation

Agriculture

As the populations of developing countries grow, the demands on the land for food, fuel, and fodder increase accordingly. Farmers then face three basic choices: they can "mine" the land—taking more out of it than they put in—until the land is exhausted; they can migrate to new lands; or they can increase the level of (capital-, energy-, and labor-intensive) agricultural inputs—mechanical traction, fertilizer, and irrigation—into the land in order to raise yields. These might also include higher inputs of information and management as might be the case for intercropping, agroforestry, integrated crop-livestock, or other sophisticated agricultural systems.[5]

Mining the Land—"Mining" the land usually takes the form of shortened fallow periods—leaving inadequate time for the natural regeneration of soil—as population pressures mount. It is obviously a temporary solution, but one often resorted to by those without access to the modern agricultural inputs needed to raise crop yields.[6] Declining yields from such "mining" are seen in a number of local and regional areas, particularly in Africa.[7]

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[5] U.S. Congress, Office of Technology Assessment, *Enhancing Agriculture in Africa: A Role for U.S. Development Assistance*, OTA-F-356 (Washington, DC: Government Printing Office, September 1988).

Migration—Many people migrate to new lands or to urban areas. In addition to population pressures or soil exhaustion, factors forcing people to migrate from long-established farming areas to new lands include the low productivity of traditional agriculture; inequities in land tenure for many subsistence farmers; drought or other disasters; and, in some areas, mechanization of agriculture and/or consolidation of agricultural lands. In many cases, currently farmed areas have been subdivided among successive generations to the point that the landholdings for those who remain are, or will soon become, marginal. In Rwanda, for example, the average smallholder had 1.2 hectares in 1984 and, by tradition, would divide it equally among his average of four sons—leaving them 0.3 hectares each. If the same trend continues, the following generation will have less than 0.1 hectare each.[8] Estimates of the number of landless or near-landless (with too little land to subsist) in developing countries range as high as 1 billion people, most of them in Asia.[9]

Wage-paying jobs are scarce for those who are forced to migrate. Land—anywhere they can get it—for subsistence agriculture and fuelwood is often their only means of survival. Increasingly, however, available lands are remote, only marginally productive, or ecologically fragile—on upland regions that are easily eroded when groundcover is removed, on arid or semi-arid lands, or in forested areas of high biological diversity (but which may have poor soils). As many as 370 million people in developing countries may live in rural areas that are ecologically vulnerable.[10] To generate good yields on a sustainable basis on these lands often requires larger inputs of labor and/or capital and technology than the lands left behind—inputs to which these people seldom have access.[11] This may be particularly true in newly opened areas where infrastructure (including access to extension efforts) is especially weak. The immigrants into these areas may be unfamiliar with the different agricultural techniques appropriate (sustainable) to these new lands and resources.

In many regions, shifting agriculture is initially practiced by those who migrate.[12] (Shifting agriculture is also practiced traditionally by "long-term" residents in many areas and is a sustainable form of agriculture if fallow periods are sufficiently long.) Shifting agriculture begins with forest-fallow systems in which small patches of land are cleared and cultivated for a few years and then left fallow for as long as two to three decades (see ch. 3). This remains an important form of agriculture in west Africa, southeast Asian hill communities, parts of South America,[13] and elsewhere.[14] This form of shifting—or slash and burn—agriculture is believed by many to be the most important cause of secondary[15] forest destruction and to be roughly comparable to commercial logging in its impact on primary forest (table 5-2).[16] Shifting cultivation consumes enormous amounts of biomass energy in the process of clearing the forest.[17]

Modern Agriculture—Those farmers with access to good soils and water resources and modern agricultural inputs can increase the yields of their croplands. Modern agricultural practices in develop-

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[6] Poor soil quality or inadequate water resources may also be significant constraints on raising crop yields even with high levels of agricultural inputs.

[7] U.S. Congress, Office of Technology Assessment, op. cit., footnote 5, pp. 63 ff.; United Nations Food and Agriculture Organization, *African Agriculture: The Next 25 Years*, Annex II, "The Land Resource Base" (Rome, Italy: United Nations, 1986).

[8] United Nations Population Fund, "The State of World Population 1990," New York, 1990.

[9] H. Jeffrey Leonard, *Environment and the Poor: Development Strategies for a Common Agenda* (New Brunswick, NJ: Transaction Books, 1989).

[10] Ibid.

[11] U.S. Congress, Office of Technology Assessment, op. cit., footnote 5.

[12] Alternatively those who migrate may continue their previous pattern of agriculture—often permanent agriculture—rather than adopting shifting agriculture techniques as traditional in the new area.

[13] Norman Myers, *Deforestation Rates in Tropical Forests and Their Climatic Implications* (London: Friends of the Earth Limited, 1989).

[14] U.S. Congress, Office of Technology Assessment, *Changing By Degrees: Steps To Reduce Greenhouse Gases*, forthcoming.

[15] Secondary forest is that which has been logged in the past and then allowed to regrow, or has otherwise been significantly affected by human activity.

[16] See also Julia C. Allen and Douglas F. Barnes, "The Causes of Deforestation in Developing Countries," *Annals of the Association of American Geographers*, vol. 75, No. 2, 1985, pp. 163-184.

[17] Kirk R. Smith, "The Biofuel Transition," *Pacific and Asian Journal of Energy*, 1987, pp. 13-32; Terry Rambo, "Human Ecology Research on Tropical Agroecosystems in Southeast Asia," *Singapore Journal of Tropical Geography*, vol. 3, No. 1, 1982. Some of the biomass ash generated serves as nutrients for the crops subsequently planted.

Table 5-2—Estimates of Land Use Changes in Closed and Open Tropical Forests, circa 1980 (million hectares per year)

	Closed forest					Open forest			
	Seiler and Crutzen		Food and Agricultural Organization	Lanly	Myers	Seiler and Crutzen		Food and Agricultural Organization	Lanly
Land use change	Low	High				Low	High		
Primary forest to:									
Shifting cultivation	2.6	3.6	3.2	3.4	1.9	—	—	1.2	1.7
Permanent pasture	1.6	1.4	1.1	2.5	0.6	1.7	2.1	0.8	1.3
Permanent agriculture	0.3	2.2	1.1	2.3	0.0	0.2	3.0	0.7	0.8
Logged forest	—	—	4.6	3.7	4.5	—	—	—	—
Logged forest to:									
Permanent pasture	—	—	1.1	—	0.6	—	—	—	—
Permanent agriculture	—	—	1.0	—	3.9	—	—	—	—
Secondary forest to:	14.9	40.0	18.5	22.0	3.4	6.9	21.9	11.4	18.6
Shifting cultivation									
Permanent pasture	0.5	1.5	0.1	—	3.3	1.0	1.0	—	—
Permanent agriculture	0.6	0.8	0.1	—	6.8	0.2	1.4	—	—

NOTE: The data in this table may be significantly inaccurate. The table is presented here only to provide a general indication of the rates and causes of deforestation. The Food and Agricultural Organization (FAO) and Lanly data are essentially the same (Lanly is the principal author of the FAO study), based primarily on official government statistics, and may be underestimates of the rate of deforestation. A more recent review by Myers, for example, indicates substantially higher rates.[1] The UNFAO currently has underway a more detailed study that may resolve some of these large discrepancies.

[1] Norman Myers, *Deforestation Rates in Tropical Forests and Their Climatic Implications* (London: Friends of the Earth, December 1989).

SOURCE: R.P. Detwiler and Charles A.S. Hall, "Tropical Forests and the Global Carbon Cycle," *Science*, vol. 239, Jan. 1, 1988, pp. 42-47, citing Seiler and Crutzen, Food and Agricultural Organization, Lanly, and Myers.

ing countries use, to varying degrees, improved plant species, synthetic fertilizers, pesticides and herbicides, irrigation, and mechanized operations to generate higher crop yields. These require high levels of capital and energy inputs.

Modern agriculture has, with mixed success, provided environmental, social, and economic benefits. It has moderated cropland expansion into ecologically fragile or particularly valuable lands through technological advance (the green revolution) and energy inputs in the form of fertilizer, irrigation, and mechanical operations. Over the 20-year period from 1965 to 1985, cropped areas increased by only 14 percent, 35 percent, and 4 percent in Africa, South America, and Asia while their populations increased by roughly 75 percent, 60 percent, and 50 percent respectively (table 5-3). Modern agriculture has also raised the personal incomes of many farmers; and it has contributed to national economic growth in many countries, especially in Asia.

Modern agriculture has also had serious shortcomings. It has increased economic inequities between those farmers who have sufficient land and access to capital and other inputs necessary for high-yield agriculture and those farmers who do not have such resources, and it has displaced laborers in many cases. It has caused environmental damage through the misuse of fertilizers, pesticides, and herbicides. Inadequate investment and poor management have led to waterlogging and salinization of valuable irrigated lands. Finally, modern agricultural techniques require dramatic increases in commercial energy use.[18] Concern over environmental impacts and high dependence on purchased inputs has led to considerable interest in farming systems that depend more on resources internal to the farming system and less on external purchases. These agricultural and agroforestry systems tend to be very information and management-intensive.[19]

Irrigated Lands—Irrigation is an important element in modern agriculture. It frees the farmer from dependence on irregular rains and raises yields, allowing double- and even triple-cropping. Some 160 million hectares of land in developing countries are irrigated. In Asia alone, 100 million hectares are irrigated, and this land produces roughly 60 percent of the region's food on just 45 percent of its cropped area.[20] In India, more than 6 million electric and 3 million diesel pump sets have been deployed (see ch. 3), consuming nearly 2,000 GWh of electricity and 3 million tons of diesel fuel in 1985.[21]

Inadequate investment and poor management have resulted in various degrees of salinization and/or waterlogging of irrigated lands in many countries. For example, by one estimate 75 percent of Pakistan's irrigated land suffers salinization and/or waterlogging, with corresponding reductions in crop yields.[22] Some 20 million hectares—roughly half—of India's irrigated croplands have sufficient salt buildup to reduce productivity; another 7 million hectares of land in India now lie unused due to excessive salt.[23] (Similar problems afflict the United States, where 20 to 25 percent of the 20 million hectares of irrigated lands are affected by salinization.[24]) Reclamation is possible through improvements in canals and other infrastructure to reduce leakage and by providing drainage from the fields, but it is expensive.

The technology to prevent or minimize salinization and waterlogging has been available since the

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[18] Note that the energy intensity of shifting—or slash and burn—cultivation may be significantly higher than commercial agriculture when the energy consumed by burning off the standing biomass is taken into account. However, commercial fuels are little used, if at all, in shifting agriculture.

[19] Advisory Committee on the Sahel, *Agroforestry in the West African Sahel*, Board on Science and Technology for International Development, National Research Council (Washington, DC: National Academy Press, 1983, 1984); U.S. Congress, Office of Technology Assessment, op. cit., footnote 5; Clive A. Edwards et al., *Sustainable Agricultural Systems* (Ankeny, Iowa: Soil and Water Conservation Society, 1990); Robert Winterbottom and Peter T. Hazlewood, "Agroforestry and Sustainable Development: Making The Connection," *AMBIO*, vol. 16, No. 2-3, 1987, pp. 100-110; C. Okali and J.E. Sumberg, "Sheep and Goats, Men and Women: Household Relations and Small Ruminant Production in Southwest Nigeria," *Understanding Africa's Rural Households and Farming Systems*, Joyce Lewinger Moock (ed.) (Boulder, CO: Westview Press, 1986).

[20] Montague Yudelman, "Sustainable and Equitable Development in Irrigated Environments," *Environment and the Poor: Development Strategies for a Common Agenda*, Jeffrey Leonard (ed.) (New Brunswick, NJ: Transaction Books, 1989).

[21] Ashok Desai, "Energy Balances for India, 1985-86," contractor report prepared for the Office of Technology Assessment, 1990. This is equivalent to 125,000 GJ.

[22] Yudelman, op. cit., footnote 20. Total crop areas from World Resources Institute, *World Resources 1990-91* (New York, NY: Oxford University Press, 1990). For other estimates, see C.E. Whitman et al. (eds.), *Rainfed Agriculture in the Near East Region*, proceedings of the workshop at Amman Jordan, Jan. 18-23, 1986, USDA and USAID, p. 92.

[23] Yudelman, op. cit., footnote 20. Total crop areas from *World Resources 1990-91*," op. cit., footnote 22.

[24] World Resources Institute, *World Resources 1987* (New York, NY: Basic Books, 1987), p. 280.

Table 5-3—Changes in Land Area Uses

Region	Total area (million hectares)	Population density, 1989 (people per thousand ha)	Cropland area		Permanent pasture		Forest/woodlands		Other land	
			1985-87 percent of total land area	1964-66 to 1983-85 percent change in cropland	1985-87 percent of total land area	1964-66 to 1983-85 percent change in pasture	1985-87 percent of total land area	1964-66 to 1983-85 percent change in forest	1985-87 percent of total land area	1964-66 to 1983-85 percent change in other uses
Africa	2,965	212	6.2	14.0	26.7	–0.5	23.2	–8.6	43.9	3.6
N. America	2,139	197	12.8	7.7	17.2	–2.4	32.0	–5.9	38.0	1.5
S. America	1,753	166	8.0	35.2	27.0	9.4	51.6	–7.3	13.4	–1.4
Asia	2,679	1,139	16.8	4.2	25.3	–3.0	20.2	–4.6	37.7	–0.7
Europe	473	1,050	29.6	–5.0	17.8	–4.9	33.2	7.1	19.4	3.9

SOURCE: World Resources Institute, *World Resources 1988-89* (New York, NY: Basic Books, 1988) table 16.1; World Resources Institute, *World Resources 1990-91* (New York, NY: Oxford University Press, 1990), table 17.1.

1950's, yet designers frequently fail to incorporate these improvements in their projects. Many factors contribute to this failure. One factor may be that designers tend to be overly optimistic in their initial appraisals: they assume that waterlogging and salinization will not occur for 20 to 30 years, and that drainage systems and other capital-intensive improvements will not be necessary before then. This lowers the apparent costs of their projects and may improve the chances that the projects will be approved.[25]

Pasture—The opening up of lands for pasture is a significant cause of deforestation (table 5-2) particularly in Central and South America where grazing lands have increased by more than 9 percent during the past 20 years (table 5-3).

Overgrazing may also play a significant role in the desertification of semi-arid regions.[26] Overgrazing and trampling can quickly destroy the grass layer. Without the protection of ground cover, topsoil can be washed or blown away, lowering fertility. In some areas, the full force of rain on the soil can bring clay particles to the surface and cause surface hardening and sealing that seeds cannot penetrate.[27] The end result of such processes can be desertification.[28]

Herders burn grasslands to encourage new growth; numerous studies have shown this new growth to be particularly good forage for their herds.[29] More generally, repeated burning is believed to help create and maintain much of the world's savannah and grassland.[30] Such brushfires in the African grasslands may burn as much as 2 billion tons of biomass annually, cause volatilization of organic nitrogen and sulfur, and allow excessive leaching of other valuable nutrients.[31] This may be particularly damaging in much of the Sahel, where growth is already strongly limited by the lack of nutrients.[32] Thus, brushfires help the herder feed his animals in the near term but, in the longer term, lower soil fertility, and kill brush and trees that hold the soils and pull nutrients up from deep in the ground.[33] Brush and grassland fires may also be significant contributors to regional air pollution and may contribute modestly to the global increase in greenhouse gases.[34]

More stable supplies of forage might reduce the need of herders to maintain large numbers of animals in order to ensure the survival of a few through periods of drought. Higher quality forage (higher protein content) would reduce the need to burn grasslands. Inputs of capital- and energy-intensive fertilizer, increased supplies of water, and mechanical harvesting of the forage (or even grain crops) when its protein content is at a maximum—as is common in industrial countries—might aid in achieving both of these goals.

Commercial Logging—Commercial logging impacts perhaps 3 to 5 million hectares of primary tropical forest annually (table 5-2). In many areas, only the highest grade logs are removed from the forest. But for every tree removed, roughly 5 to 10 other trees are destroyed.[35] Commercial logging also develops roads that allow settlers access to forested regions, where they can clear the forests for farms or ranches.

Biomass Fuels—Biomass—wood, crop residues, and animal dung—is the primary fuel for people in rural areas, and in many regions it is also important for the urban poor (see ch. 3). Until recently, it was widely believed that many developing countries were on the verge of being transformed into treeless deserts or mountain wastelands due to the demand for fuelwood. These predictions were largely based on the "gap" model, which assumed a fixed per-capita demand for fuelwood and a growing population while at the same time the forest base was declining due to agricultural expansion and over-cutting of the forest.[36]

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[25] Yudelman, op. cit., footnote 20.

[26] William H. Schlesinger et al., "Biological Feedbacks in Global Desertification," *Science*, vol. 247, Mar. 2, 1990, pp. 1043-1048.

[27] National Research Council, Board on Science and Technology in Development, *Agro Forestry in the West African Sahel* (Washington, DC: National Academy of Sciences, 1983); Georges Novikoff and Mohamed Skouri, "Balancing Development and Conservation in Pre-Saharan Tunisia," *AMBIO*, vol. 10, Nos. 2-3, 1981, pp. 135-141.

[28] United Nations Food and Agricultural Organization, *African Agriculture: The Next 25 Years*, Annex II, "The Land Resource Base," op. cit., footnote 7.

[29] J. Dirck Stryker, "Technology, Human Pressure, and Ecology in the Arid and Semi-Arid Tropics," in H. Jeffrey Leonard (ed.), op. cit., footnote 9.

[30] Carl Sagan, Owen B. Toon, and James B. Pollack, "Anthropogenic Albedo Changes and the Earth's Climate," *Science*, vol. 206, 1979, pp. 1363-1368; Daniel Finn, "Land Use and Abuse in the East African Region," *AMBIO*, vol. 12, No. 6, 1983, pp. 296-301; D.J. Pratt and M.D. Gwynne (eds.), *Rangeland Management and Ecology in East Africa* (Huntington, NY: Robert E. Kreiger Publishing Co., 1977).

[31] National Research Council, Board on Science and Technology in Development, *Environmental Change in the West African Sahel* (Washington, DC: National Academy of Sciences, 1983); World Resources Institute, *World Resources 1990-91* (New York, NY: Oxford University Press, 1990).

[32] H. Breman and C.T. deWit, "Rangeland Productivity and Exploitation in the Sahel," *Science*, vol. 221, 1983, pp. 1341-1347.

[33] Stryker, op. cit., footnote 29.

[34] World Resources Institute, *World Resources 1990-91* (New York, NY: Oxford University Press, 1990).

[35] Fred Pearce, "Hit and Run in Sarawak," *New Scientist*, May 12, 1990, pp. 46-49.

In more recent studies, however, it has been found that the use of fuelwood is highly elastic according to its availability and the labor required to collect it or, if traded, its price. When fuelwood is difficult to obtain by foraging, people quickly resort to lower quality wood, agricultural residues, or dung. More generally, rural subsistence farmers cause relatively little damage to forests, as they usually take only deadwood or small limbs. They do not have the tools to cut down large trees. Much of the wood they collect is from hedgerows or other sources near their farms. In Kenya, for example, trees outside the forest supply half the fuelwood demand.[37] And in West Java, one study found that three-fourths of all the fuel collected came from within family courtyards and gardens, and two-thirds of this fuel was branches and twigs.[38]

In contrast to rural foragers, commercialized fuelwood and charcoal operations to supply urban households, commercial facilities and industrial operations often cut whole trees and can damage or destroy forested areas. The impact of commercial demands for fuelwood are limited, however, as users will switch to fossil fuels when fuelwood becomes scarce and prices climb (ch. 3).[39] The extent of the damage to the forest resulting from commercialized fuel demand will then depend on the distance between the user and the forest, the size of the forest, the size of the demand, the rate of regrowth, and other factors. The use of biomass for fuel is not usually a principal cause of deforestation. It does, however, add additional pressure on forest resources. In arid or semi-arid regions, where forest growth is slow and there is a high population density or a concentrated urban demand for fuelwood, such as the African Sahel, the use of biomass fuels can contribute significantly to local deforestation.[40] Similarly, the use of biomass fuels can lead to local deforestation in some cases where there is a concentrated commercial or industrial demand.

Environmental Impacts

The environmental impacts of agriculture, ranching, lumbering, and the use of biomass for fuel include deforestation, desertification, soil erosion, flooding, pesticide and fertilizer runoff from cropland, and air pollution from biomass fuels.

Deforestation[41]

The forests of the developing world provide a number of resources and benefits, including food, fuel, fodder, fiber, timber, and medicines. Forests are a vital ecological resource, protecting soils, maintaining diverse plant and animal life, regulating the flow of water, and playing an important role in the global carbon cycle. Forests may also strongly influence regional climates.[42] The loss of tropical forests not only threatens to deprive the world of valuable resources on which it currently depends, but also to foreclose opportunities to discover new potential sources of wealth and scientific knowledge. On the other hand, tropical forests offer an economic opportunity that the poor in developing countries wish to seize as quickly as possible.[43] Governments may also want to colonize forest lands in order to establish more clearly their legal claim to national territory.

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[36] Gerald Foley, "Discussion Paper on Demand Management," proceedings of the ESMAP Eastern and Southern Africa Household Energy Planning Seminar, Harare Zimbabwe, Feb. 1-5, 1988, UNDP/World Bank Energy Sector Management Assistance Program, Activity Completion Report No. 085/88.

[37] Phil O'Keefe, "Fuel for the People: Fuelwood in the Third World," *AMBIO*, vol. 12, 1983, pp. 21-26.

[38] M. Hadi Soesastro, "Policy Analysis of Rural Household Energy Needs in West Java," *Rural Energy to Meet Development Needs: Asian Village Approaches*, M. Nurul Islam, Richard Morse. and M. Hadi Soesastro (eds.) (Boulder, CO: Westview Press, 1984), p. 114.

[39] Douglas F. Barnes, "Understanding Fuelwood Prices in Developing Nations," draft, Household Energy Unit, Industry and Energy Department, World Bank, Washington, DC, Oct. 31, 1989.

[40] Douglas F. Barnes, World Bank, "Population Growth, Wood Fuels, and Resource Problems in Sub-Saharan Africa," Industry and Energy Department Working Paper No. 26, March 1990; R. Moss and W. Morgan, *Fuelwood and Rural Energy Production and Supply in the Humid Tropics* (Dublin, Ireland: Tycooly International Publishing Ltd., 1981); Finn, op. cit., footnote 30; Dennis Anderson and Robert Fishwick, World Bank, "Fuelwood Consumption and Deforestation in African Countries," World Bank Staff Working Paper, No. 704, 1984.

[41] For detailed reviews of deforestation and policy responses to it, see: U.S. Congress, Office of Technology Assessment, *Changing By Degrees: Steps To Reduce Greenhouse Gases*, forthcoming; U.S. Congress, Office of Technology Assessment, *Technologies to Sustain Tropical Forest Resources*, OTA-F-214 (Springfield, VA: National Technical Information Service, March 1984); and Robert Winterbottom, "Taking Stock: The Tropical Forestry Action Plan After Five Years," World Resources Institute, Washington, DC, June 1990.

[42] J. Shukla, C. Nobre, and P. Sellers, "Amazon Deforestation and Climate Change," *Science*, vol. 247, Mar. 16, 1990, pp. 1322-1325.

The rate of global deforestation—from all causes—is highly uncertain, with estimated rates in the early 1980s ranging from roughly 0.5 percent[44] to 1.8 percent[45] annually. These rates appear to be accelerating due to increasing population and other pressures noted above.

The UNFAO 1990 Forest Resources Assessment estimates the current annual global deforestation rate as 1.2 percent—double their estimate for 1980.[46] Forested areas and deforestation rates vary widely between countries. Indonesia and Brazil have huge areas of closed forests (100 and 350 million hectares, respectively) and annual rates of deforestation of perhaps 0.4 to 1.4 percent and 0.5 to 2.3 percent, respectively. Aggregate figures, however, tend to obscure severe deforestation occurring in certain regions. Ivory Coast, for example, has just 16 million hectares of forest remaining, and suffers an annual deforestation rate variously estimated between 6.5 and 15.6 percent. A number of other countries lie between these extremes, with forested areas of 5 to 50 million hectares and deforestation rates variously estimated in the range of 2 to 8 percent annually.[47] At these rates, their closed forests could disappear in a few decades.

Desertification

Desertification can result from a variety of factors, depending on the region, including long-term climate trends, overgrazing, poor farming practices, and deforestation.[48] Although anecdotal evidence indicates that drylands in many regions are becoming desertified at an increasing rate, there is little reliable data to support the case. The "Global Assessment of Soil Degradation," initiated in late 1987 by the United Nations Environmental Program and the International Soil Reference and Information Centre in the Netherlands, should provide some of these data.

Impacts of Deforestation and Desertification

Among the potential impacts of deforestation and desertification are soil erosion and degradation, fuelwood and fodder shortages, increased flooding, microclimatic changes, and loss of biodiversity.[49]

Soils—Little soil is lost from forests or grasslands. When vegetation is removed, massive amounts of soil can be washed away as rainwater flows across the surface. Measurements in Tanzania indicated that up to half the rainfall was lost as runoff from bare fallow (3.5° slope), carrying with it some 70 tons of soil per hectare.[50] Similar impacts have been noted elsewhere.[51] With no shading, soil temperatures rise dramatically and can greatly reduce the vital biological activity in the soil.[52] Loss of tree cover also allows higher average wind velocities (and soil erosion) and, combined with the reduced soil moisture content, can lower crop yields.[53]

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[43] Ricardo Radulovich, "A View on Tropical Deforestation," *Nature*, vol. 346, July 19, 1990, p. 214.

[44] Jean-Paul Lanly, "Tropical Forest Resources," Forestry Paper No. 30, United Naticns Food and Agriculture Organization, Rome 1982.

[45] Myers, op. cit., footnote 13.

[46] "World Deforestation Increases at Quicker Rate Than Expected," *Multinational Environmental Outlook*, Aug. 21, 1990, p. 134.

[47] Myers, op. cit., footnote 13, p. 284.

[48] G. Novikoff, "Desertification by Overgrazing," *AMBIO*, vol. 12, No. 2, 1983, pp. 102-105; H.F. Lamprey and Hussein Yussuf, "Pastoralism and Desert Encroachment in Northern Kenya," *AMBIO*, vol. 10, Nos. 2-3, 1981, pp. 131-134; National Research Council, *Environmental Change in the West African Sahel*, op. cit., footnote 31; D. Anderson, and R. Fishwick, "Fuelwood Consumption and Deforestation in African Countries," World Bank, Staff Working Paper No. 704, 1984; Schlesinger et al., op. cit., footnote 26.

[49] Kuswata Kartawinata et al., "The Impact of Man of a Tropical Forest in Indonesia," *AMBIO*, vol. 10, Nos. 2-3, 1981, pp. 115-119; Lester R. Brown, "World Population Growth, Soil Erosion, and Food Security," *Science*, vol. 214, 1981, pp. 995-1002; Alain Grainger, *Desertification* (London: Earthscan, 1984), p. 94.

[50] Phil O'Keefe, "The Causes, Consequences and Remedies of Soil Erosion in Kenya," *AMBIO*, vol. 12, No. 6, 1983, pp. 302-305.

[51] U.S. Congress, Office of Technology Assessment, op. cit., footnote 41; Finn, op. cit., footnote 30; *Eneas Salati and Peter B. Vose*, "Depletion of Tropical Rainforests;" *AMBIO*, vol. 12, No. 2, 1983, pp. 67-71, Vaclav Smil, "Deforestation in China," *AMBIO*, vol. 12, No. 5, 1983, pp. 226-231; Nigel J.H. Smith, "Colonization Lessons from a Tropical Forest," *Science*, vol. 214, 1981, pp. 755-761; A.H. Gentry and J. Lopez-Parodi, "Deforestation and Increased Flooding of the Upper Amazon," *Science*, vol. 210, 1980, p. 1354.

[52] Salati and Vose, op. cit., footnote 51; Henri Dosso, Jean Louis Guillaumet, and Malcolm Hadley. "Land Use Problems in a Tropical Forest," *AMBIO*, vol. 10, No. 2-3, 1981.

[53] Dennis Anderson, "Declining Tree Stocks in African Countries," *World Development*, vol. 14, No. 7, 1986, pp. 853-863.

Fuel and Fodder—As forests and grasslands disappear, rural people are increasingly forced to rely on agricultural residues and dung for their cooking and heating needs, and on crop residues for animal fodder. The failure to return organic materials to the soil can have significant environmental impacts, even if these impacts are longer term and more subtle than is sometimes suggested. People in many areas already divert organic residues to other uses, often with little apparent near-term effect on yields. For example, crop residues such as millet or sorghum stalks tend to be poor fertilizers and are difficult to recycle; they are often burned in the fields to prevent them from harboring crop pests. Similarly, dung quickly loses its nitrogen and much of its effectiveness as a fertilizer when left lying in the sun, as is common.[54] In areas with poor soils and/or high rainfalls that quickly leach nutrients out, however, crop yields may drop quickly if residues are not returned to the soil.

In the longer term, the loss of organic material can reduce the productivity of even the highest quality soils. Organic matter in soils provides important nutrients needed by plants; it helps the soil bind important minerals—e.g., magnesium, calcium, and potassium—that would otherwise be leached away; it buffers the acidity of the soil; and it improves water retention and other physical characteristics.[55]

Water—When the natural water regulation system provided by forests and grasslands is removed, stream flows tend to become more erratic, with reduced flows during dry seasons and worse floods in the wet season. This can interfere with agriculture, fishing, and dams and can threaten inhabitants. Eroded soils choke downstream waterways and reservoirs, reducing their ability to handle the increased volumes of water running directly off the watersheds.[56] Over the past 10 years, the area annually flooded in India has increased by 18 percent.[57] Some observers attribute this increased flooding to the clearing of regional forests. Flood and erosion damage due to the clearing of India's forests has been estimated at $20 billion for the period from roughly 1960 to 1980, including loss of topsoil, loss of property to floods, and shortened reservoir lifetimes (table 5-4).[58] Other estimates place the direct costs of repairing flood damage in India at more than $250 million per year.[59]

Table 5-4—Sedimentation Rates of Some Reservoirs in India

	Lifetime (years)	
Reservoir	Planned	Revised
Bhakra	88	47
Maithon	246	24
Hirakund	100	35
Ram Ganga	185	48

SOURCE: Kunwar Jaleee, "Loss of Productive Soil in India," *International Journal of Environmental Studies*, vol. 24, 1985, pp. 245-250.

Climate—In some regions, a significant portion of the rainfall is generated from moisture pumped back into the atmosphere by vegetation. Removal of this vegetation may then contribute to climatic change in the region.[60] The surface reflectance is changed and may likewise affect climate.[61] To the extent that the local climate changes due to the loss of vegetation, it may become more difficult to reverse the process and restore grasslands and forests to something approaching their original form and extent.[62]

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[54] G.C. Aggarwal, "Judicious Use of Dung in The Third World," *Energy*, vol. 14, No. 6, 1989, pp. 349-352.

[55] Geoffrey Barnard and Lars Kristoferson, *Agricultural Residues as Fuel in The Third World* (London: Earthscan, 1985.

[56] Erik P. Eckholm, *Losing Ground: Environmental Stress and World Food Prospects* (New York, NY: W.W. Norton & Co., 1976).

[57] U.S. Congress, Office of Technology Assessment, op. cit., footnote 41.

[58] Ibid. A more general review of this problem in India is given in *The State of India's Environment 1984-84; The Second Citizen's Report* (New Delhi: Center for Science and Environment).

[59] John Spears, "Preserving Watershed Environments," *UNASYLVA*, vol. 34, No. 137, 1982, pp. 10-14.

[60] Sagan et al., op. cit., footnote 30; J. Shukla and Y. Mintz. "Influence of Land-Surface Evapotranspiration on the Earth's Climate," *Science*, vol. 215, 1982, pp. 1498-1501.

[61] Robert S. Kandel, *Mechanisms Governing the Climate of the Sahel: A Survey of Recent Modelling and Observational Studies*, OECD/CILSS/Club du Sahel, Report Sahel D(84)?252, October 1984. See also Sagan et al., op. cit., footnote 30, estimates of albedo changes are given in Gregory Morris, "Environmenial Impacts of Bioenergy Development," *Biomass Energy Systems: Building Blocks for Sustainable Agriculture*, Jan. 29-Feb. 1, 1985, Airlie House, Airlie, VA, The Rockefeller Brothers Fund and World Resources Institute, Washington, DC.

Biodiversity[63]—Plants in tropical rain forests have evolved a particularly rich array of potentially useful chemicals, yet fewer than 1 percent of all tropical plant species have so far been screened for biochemicals of use to man.[64] A number of valuable medical products have already been developed from tropical plants, including highly effective drugs for leukemia and hypertension, muscle relaxants, and others.[65] Many other aesthetic, scientific, and commercial benefits may be realized from tropical forest products. Tropical deforestation and the loss of species would foreclose many of these opportunities.[66]

Although they have received much less attention, plants in arid and semi-arid regions similarly offer many potential benefits. These areas harbor a number of wild relatives to our basic crops—beans, potatoes, wheats, barleys, millets, sorghums, and many others—and are sources for genetic resistance to drought, heat, pests, and disease. The diverse genetic resources of wild varieties can be an important input into the higher yielding but genetically narrow varieties used in intensive agriculture. Many valuable genetic strains and species may be at risk in these arid and semi-arid regions.[67]

Deforestation can result in a direct conflict between the survival of species and the livelihoods of people who exploit the land. Such a conflict recently erupted in the United States over the endangered northern spotted owl.[68] There are similar conflicts in many developing countries. Tropical rain forests contain at least half and perhaps as many as 90 percent or more of the species found on earth, yet cover just 7 percent of the total land area. No one knows precisely the share of species held by tropical rain forests, because fewer than 2 million species have been officially classified out of a total number that is variously estimated to range from less than 5 to more than 50 million.[69] Many countries are taking steps to protect their biodiversity, and a few are realizing some success. Protection of the brow-antlered deer in northeast India, for example, is helping it make a comeback from near extinction.[70]

There are concerns in developing countries, however, that the costs of conserving biodiversity—in jobs and/or access to land and resources for the poor, security enforcement, administration, and the mistrust generated as governments deny their own people access to much-needed resources—will be born by the developing countries, but the benefits will be largely captured by commercial interests in industrialized countries.[71]

Air Pollution

The burning of biomass generates large amounts of air pollution in developing countries. Food is typically cooked over an open fire or a poorly vented stove—exposing women and children, as well as other members of the family, to high levels of toxic smoke (ch. 3). Similarly, in colder climates, homes in rural areas are often heated by open fires, further increasing exposures to toxic smoke.[72] One impact of this indoor air pollution is exacerbation of one of the most deadly classes of infectious illness, acute respiratory infections in children.

The use of biomass for fuel, clearing forest land for agriculture, and burning grasslands to generate fresh forage for livestock all generate large amounts of smoke that contributes to regional air pollution. These activities also pump greenhouse gases into the atmosphere, potentially contributing to global climate change.[73] This is discussed in much more detail in the forthcoming OTA report, *Changing By Degrees: Steps To Reduce Greenhouse Gases.*

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[62] J. Shukla, C. Nobre, P. Sellers, "Amazon Deforestation and Climate Change" *Science*, vol. 247, Mar. 16, 1990, pp. 1322-1325. H. Schlesinger et al., op. cit., footnote 26.

[63] For a complete review of this complex issue, see U.S. Congress, Office of Technology Assessment, *Technology to Maintain Biological Diversity*, OTA-F-330 (Springfield, VA: National Technical Information Service, March 1987).

[64] Neil A. Belson, "Tropical Deforestation and the Response of the United States Congress," *Georgetown International Environmental Law Review*, vol. 2, Fall 1989; U.S. Congress, Office of Technology Assessment, op. cit., footnote 41.

[65] U.S. Congress, Office of Technology Assessment, op. cit., footnote 41.

[66] Edward O. Wilson, "Threats to Biodiversity," *Scientific American*, September 1989, pp. 108-116; Walter V. Reid and Kenton R. Miller, *Keeping Options Alive: The Scientific Basis for Conserving Biodiversity* (Washington, DC: World Resources Institute, October 1989).

[67] Gary Nabhan, "How Are Tropical Deforestation and Desertification Affecting Plant Genetic Resources," *Annals of Earth*, vol. 4, No. 1, pp. 21-22, 1986; Paul Raeburn, "Seeds of Despair," *Issues in Science and Technology*, Winter 1989-90, pp. 71-76.

[68] Library of Congress, Congressional Research Service, "Economic Impacts of Protecting the Northern Spotted Owl," 90-74 ENR, Mar. 5, 1990.

[69] Robert M. May, "How Many Species Are There on Earth," *Science*, Sept. 16, 1988, pp. 1441-1449.

[70] Sanjoy Hazarika, "A Deer Comes Back From the Brink in India," *New York Times*, July 31, 1990.

[71] Ricardo Radulovich, "A View on Tropical Deforestation," *Nature*, vol. 346, July 19, 1990, p. 214.

[72] Kirk R. Smith, *Biofuels, Air Pollution, and Health: A Global Review* (New York, NY: Plenum Press, 1987).

The Urban Sector

Causes of Environmental Degradation

Urban areas of developing countries are growing rapidly, in large part due to migration from rural areas. For the low-income countries, urban population jumped from 17 percent of total population in 1965 to 30 percent in 1987. In 1960, there were 59 cities with more than 500,000 persons in developing countries; by 1980 that number had grown to 165 cities.[74] In the early 1990's, cities in developing countries will need to absorb more than 100 million additional people annually.[75] This trend has important implications for both energy use and energy-related environmental impacts.

Urbanization and modernization can provide many desirable benefits—improved standards of living, increased opportunities for education and employment, and greater insulation from the vagaries of drought endured by those in rural areas. (They also reduce pressures on some aspects of the rural environment.) They also have costs, including potential damage to the environment.

Urbanization changes the consumption patterns of goods and energy-related services (ch. 3). Households make a transition from biomass to commercial fuels for cooking and other domestic services. Demand for consumer goods, notably electric appliances, increases. The economic base changes from agriculture and small rural industry to larger manufacturing and services, with a corresponding change in the demand for commercial energy. The need for public and personal transport grows as employment shifts from agriculture or rural industry located within walking distance of residences to large industry and commerce located further away. The high concentration of people requires the transport of food, fuel, and other materials from long distances, as well as effective management of wastes. These changes have significant impacts on energy use and on the environment.

Residential/Commercial Sector

The transition from biomass to clean commercial fuels such as liquefied petroleum gas (LPG) and electricity for residential cooking generally reduces the total amount of air pollution emitted and largely shifts that which is emitted from the household to distant refineries and electricity generation plants (ch. 3).[76] In some countries, however, clean commercial fuels are not widely available or remain too expensive. China, for example, uses about one-third of its coal in residences, of which nearly half is used for cooking (app. 3-A). Due in part to heavy residential coal use, some northern Chinese cities, such as Beijing and Tianjin, have very high sulfur dioxide concentrations.

Lights, refrigerators, air conditioners, and other electrical appliances in the residential/commercial sector provide highly desirable services and are penetrating urban areas much more rapidly than rural areas (ch. 3). These appliances consume large amounts of electricity, however, the generation of which can cause significant environmental damage if not properly controlled. Refrigerators and air conditioners also use chlorofluorocarbons (CFCs), which have already damaged the earth's protective ozone layer and are potent greenhouse gases.

Industrial Sector

Industry provides many goods that contribute to our material comfort and well-being. Industry can damage the environment through a variety of activities, however, if they are mismanaged or inadequately controlled. These include: placing heavy demands on natural resources as feedstocks or other inputs; intensively using electricity for mechanical drive and other needs; burning fossil fuels for process heat; and generating hazardous wastes that may be discharged into landfills, water systems, or the air. Each industry has a different mix of these activities, and each activity has a different set of environmental impacts, depending on the use of environmental controls and other means of mitigation.

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[73] R.P. Detwiler and Charles A.S. Hall, "Tropical Forests and the Global Carbon Cycle," *Science*, vol. 239, Jan. 1, 1988, pp. 42-47; Richard A. Houghton, "The Future Role of Tropical Forests in Affecting the Carbon Dioxide Concentration of the Atmosphere," *AMBIO*, vol. 19, No. 4, July 1990, pp. 204-209.

[74] World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989).

[75] *World Development Report 1990*, op. cit.; Indicator Tables 1 and 31. The urban population—41 percent of the developing country total of 3.95 billion people—1.6 billion people and is growing at 6.9 percent annually.

[76] This refers to carbon monoxide, particulates, sulfur dioxide, nitrogen oxides, and other such chemical species. It does not refer to carbon dioxide, which may be increased by the use of nonbiomass fuels but not by biomass if the biomass is being produced on a sustainable basis.

Industrial pollution can pose a particularly severe health hazard in developing countries when industries are established near existing residential areas, or when residential areas build up around them. This has led to tragedies such as Bhopal, as well as serious systemic pollution such as found in Cubatao, Brazil, in the 1970's and early 1980's.[77] Often, the lowest income people are most seriously affected. This can lead to the situation in which the poor face all of their traditional risks to health—infectious disease, hunger and malnutrition, air pollution from biomass fuels—and at the same time face even greater than normal modern risks—such as exposure to hazardous wastes and toxic air pollutants.[78]

Transportation Sector

The transportation sector is the largest contributor to air pollution in many cities. For example, in Indian cities, gasoline-fueled vehicles—mostly two and three wheelers—are responsible for 85 percent of carbon monoxide and 35 to 65 percent of hydrocarbons in the air from fossil fuels.[79] Diesel vehicles—buses and trucks—are responsible for over 90 percent of nitrogen oxide (NO_x) emissions in urban India.[80] Use of emission control devices and engine modifications have significantly reduced exhaust emissions on newer vehicles in the United States, but these pollution controls are usually not standard on vehicles in developing countries. Runoff from roads also contributes to water pollution.

In each of these sectors, there are often difficult tradeoffs between longer term environmental impacts and immediate financial costs to consumers. Many developing countries also have shortages of skilled technical manpower to implement mitigation efforts. The extent to which technological innovations or other advances might ease these tradeoffs will be examined in a later report of this OTA study.

Environmental Impacts

Air

Air quality in many of the developing world's cities is poor, and has been deteriorating. The United Nations Environment Program (UNEP) estimates that up to one-half of the world's urban population, including residents of many industrialized countries, live in areas with marginal or unacceptable levels of sulfur dioxide (SO_2) in the air. Concentrations of SO_2 (see figure 5-1) and concentrations of total suspended particulates (see figure 5-2) in major cities in the developing world are considerably above World Health Organization guidelines. Photochemical smog has become a recurrent seasonal problem in many large tropical and subtropical cities.

The sources of these pollutants vary. Coal—used for electricity generation, industrial power and process heat, and domestic heating and cooking (China)—primarily emits sulfur dioxide, particulates, and nitrogen oxides. The combustion of oil or gas in stationary sources, such as electric generating units, emits many of the same pollutants—nitrogen oxides, hydrocarbons, particulates, and sulfur dioxide—but in much different proportions.[81] Nitrogen oxide, a major ingredient of urban smog, is the most harmful pollutant released on a large scale when electricity is generated from oil or gas. Mobile sources—cars, trucks, two and three wheelers, and buses—release large amounts of carbon monoxide, NO_x, hydrocarbons, and particulates and are typically the largest source of these pollutants in urban areas. These mobile sources are also major contributors of lead pollution due to the use of lead as an octane booster in gasoline. Burning fossil fuels unavoidably generates carbon dioxide, the most important greenhouse gas. These pollutants (except carbon dioxide (CO_2)) can damage crops, forests, and structures and can aggravate human health problems.

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[77] World Resources Institute, *World Resources 1990-91* (New York, NY: Oxford University Press, 1990), p. 41.

[78] In the more general case, there is a shift in the types of risk that people are exposed to from the traditional to the modern. See Kirk R. Smith, "The Risk Transition," *International Environmental Affairs*, vol. 2, No. 3, in press.

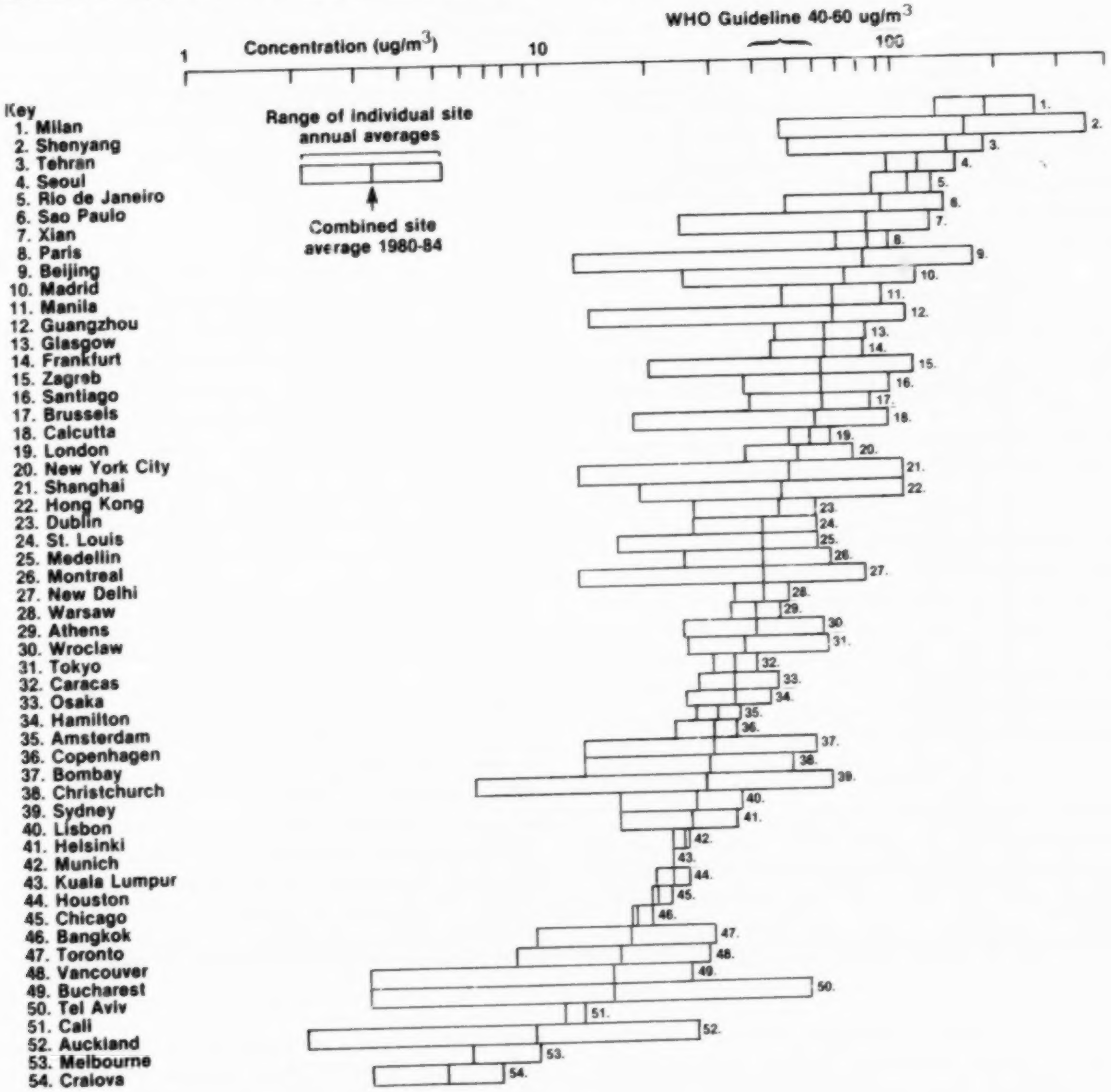
[79] Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook 1988* (New Delhi, India: 1989), p. 250.

[80] Ibid.

[81] Mitre Corp., "Health and Environmental Effects of Oil and Gas Technologies: Research Needs," report to the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, July 1981.

Figure 5-1—Sulfur Dioxide Levels in Selected Cities, 1980-84

Shown is the range of annual values at individual sites and the composite 5-year average for the city.

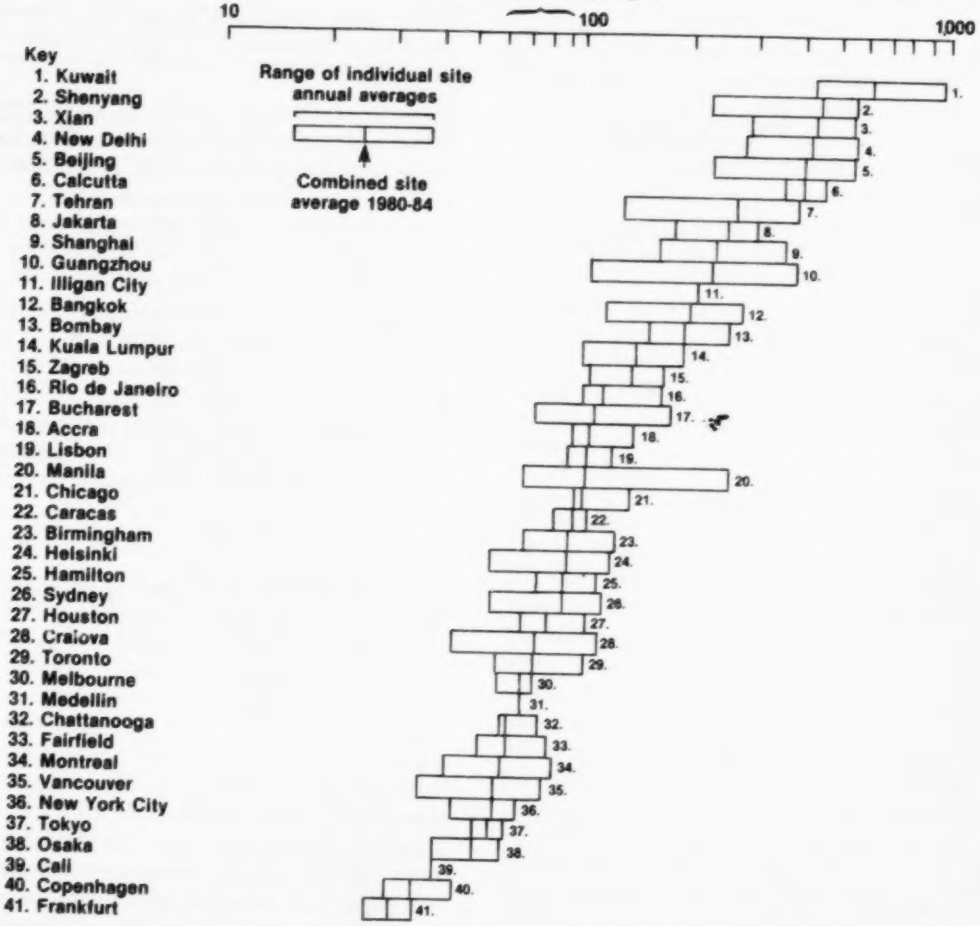


[a]Note logarithmic scale.

SOURCE: World Health Organization and United Nations Environment Programme, *Global Pollution and Health* (London: Yale University Press, 1987), figure 2, p. 5. (Logarithmic scale.)

Figure 5-2—Suspended Particulate Matter Levels in Selected Cities, 1980-84

Shown is the range of annual values at individual sites and the composite 5-year average for the city.



[a]Note logarithmic scale.

SOURCE: World Health Organization and United Nations Environment Programme, *Global Pollution and Health* (London: Yale University Press, 1987), figure 3, p. 6. (Logarithmic scale.)

Efforts to reduce emissions from coal burning usually involve removing harmful material from exhaust gases after combustion. Pollution controls, such as electrostatic precipitators or baghouses to control particulates, capture pollutants from exhaust gases, but they create solid wastes in the process. Flue gas desulfurization (FGD) equipment ("scrubbers") controls sulfur emissions by capturing the sulfur in the form of liquid sludges. Electrostatic precipitators are widely used in the developing world, but FGD systems are not common.[82] This may be due in part to the high costs of such systems. One study in India found that the addition of an FGD system would add about 15 percent to the cost of electricity.[83] Perhaps as significant is that Indian and Chinese coals have relatively low sulfur contents—typically 0.5 to 2.0 percent compared to 3 to 6 percent for Eastern European and some U.S. coals.[84]

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[82] International Development and Energy Associates, Inc., "Clean Coal Technologies for Developing Countries," contractor report prepared for the Office of Technology Assessment, May 1990, p. 25.

Adoption of more effective pollution control technologies already common in the industrialized world and improvements in energy efficiencies might significantly improve air quality in many cities of the developing world.

Water

The primary urban water pollution problem is the discharge of untreated or minimally treated human waste into water systems (this is also a significant problem in rural areas). As of the mid-1980's, only about half the developing world's urban population had adequate sewage facilities, and perhaps three-fourths had access to safe drinking water. This situation contributes to the growth and spread of pathogenic viruses, bacteria, and protozoa and is directly or indirectly responsible for perhaps three-fourths of all illness and 80 percent of all child deaths.[85]

Industrial wastes also contribute significantly to water pollution in some areas. These range from agricultural industry wastes to heavy metals (mercury, cadmium, lead, and chromium) and chlorinated hydrocarbons—to name only a few. These pollutants can have serious impacts on water resources all the way downstream to the ocean. Many coastal areas are also being affected.[86] A recent study found that World Health Organization (WHO) standards for heavy metals—cadmium, lead, and mercury—were exceeded in one-third to three-fourths of the fish and shellfish samples taken from Jakarta Bay, Indonesia.[87] Mitigation strategies that might be applied include treatment of industrial effluents and reduction of the generation of hazardous materials themselves through improvements in manufacturing processes.[88]

Land

The major causes of soil pollution in urban areas are the disposal of solid wastes and the deposition of air pollutants such as SO_2 and particulates. The focus here is on solid wastes. Low-income countries generate much less urban refuse (around 0.5 kg per capita per day) than industrial countries (0.7 to 1.8 kg per capita per day).[89] In large cities, however, even modest per-capita levels can lead to large amounts of waste generation. Mexico City is estimated to generate 11,000 tons a day. Most of this waste originates from households, largely in the form of vegetable and putrescible materials. There is also a significant component of hazardous wastes (containing chemicals, heavy metals, and/or radioactive wastes) from industries.

In the developing countries, current procedures for disposing of such wastes are inadequate. Much household garbage is not collected at all, but left to decompose. Hazardous wastes may be dumped on uncontrolled municipal landfills. Only a small part of total wastes are disposed of in an environmentally safe manner. Nonetheless, costs of even inadequate disposal can amount to as much as 30 percent of municipal budgets.[90]

Energy could, however, play a part in solving these problems. Urban waste can be used as feedstock for cogeneration plants. Process changes in energy-intensive industries such as steel, cement, and fertilizer may well, by economizing on the use of all materials, also reduce hazardous wastes.

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[83] Ibid., p. 25.

[84] Ibid., pp. 7, 8, 27.

[85] World Resources Institute, *World Resources 1990-91* (New York, NY: Oxford University Press, 1990); World Resources Institute, "Development and Pollution in the Third World," Tokyo Conference on the Global Environment and Human Response, Sept. 11-14, 1989; World Health Organization, *The International Drinking Water Supply and Sanitation Decade* (Geneva: United Nations, 1986); World Health Organization and United Nations Environment Programme, *Global Pollution and Health* (New Haven, CT: Yale University Press, 1987).

[86] United Nations Environment Programme, "The State of the Marine Environment," 1990.

[87] World Resources Institute, "Development and Pollution in the Third World," op. cit., footnote 85.

[88] U.S. Congress, Office of Technology Assessment, *Serious Reduction of Hazardous Waste For Pollution Prevention and Industrial Efficiency*, OTA-ITE-317 (Washington, DC: U.S. Government Printing Office, September 1986). U.S. Congress, Office of Technology Assessment, *From Pollution to Prevention: A Progress Report on Waste Reduction*, OTA-ITE-347 (Washington, DC: U.S. Government Printing Office, June 1987).

[89] Sandra J. Cointreau, *Environmental Management of Urban Solid Wastes in Developing Countries: A Project Guide*, quoted in "Development and Pollution in the Third World," prepared by The World Resources Institute for the Tokyo Conference on the Global Environment and Human Response, Sept. 11-14, 1989 (Washington, DC: World Resources Institute, July 1989).

[90] World Resources Institute, *World Resources 1988-89* (New York, NY: Basic Books, Inc., 1988), p. 46.

Energy Production and Conversion

Energy plays a critical role in fueling the transition from a traditional to a modern society and thus aiding economic and social development. In turn, this energy is extracted from rural areas—either as fossil fuels or renewable energy—and can have significant impacts on the rural economy and environment. Energy thus provides an important two-way linkage between rural and urban areas.

Used wisely, energy can provide environmental benefits; if misused it can also exact substantial environmental costs to the land, water, and air. The many social, economic, and environmental benefits have been reviewed in the preceding chapters; the environmental costs of extracting and transporting the major energy resources used in developing countries today—coal, oil, gas, hydroelectricity, and biomass—are briefly reviewed below.

Coal

Coal has significant environmental effects throughout the fuel cycle.[91] The environmental effects of coal mining depend on the techniques used. Mining methods are selected according to the depth of the coal, the thickness of the seams, and the availability of capital and equipment. In surface mining, topsoil and overburden are removed to expose the coal. The mining process can disturb surface lands and waters, and may also contaminate or disturb underground aquifers. Increased erosion, downstream siltation, and water contamination can follow if excavated material is not properly managed during mining. Soil productivity and water resources can be degraded if lands are not reclaimed adequately. The most severe impacts associated with underground mining are surface subsidence over mined-out areas, disruption of aquifers, and contamination of water by acid drainage. Additionally, dust and emissions from coal mining, preparation, and transport or related equipment can contribute to local air pollution.[92]

Oil and Gas

Oil and gas production have similar environmental impacts. During exploration and production, the major environmental concerns onshore include land disturbances, aquifer contamination, leaks and spills, and disposal of liquid and solid wastes. For offshore operations, concerns include the impacts of operations on fisheries and marine habitats, leaks and spills, and waste disposal.

Large spills of oil or petroleum products, which occasionally occur during production, storage, or transportation, are perhaps the most dramatic environmental threat associated with oil production. Small leaks and spills are much more common, however, and may have a greater overall impact on the environment. Oil spills can poison fish and aquatic animal and plant life. Additionally, sediments can trap oil, creating a long-term source of pollution. The well-publicized Alaskan oil spill of 1989 revealed the difficulties inherent in cleaning up large oil spills in difficult ocean environments.[93] Developing countries have had their share of oil spills too. The June 1979 blowout of the IXTOC I production well in the Mexican Caribbean was the largest oil spill to date.[94] It released an estimated 139 to 428 million gallons of crude oil into surrounding waters, as much as 40 times the amount spilled by the Exxon Valdez. Natural gas leaks pose little toxic threat to plants and animals but can explode or cause fires. The primary constituent of natural gas—methane—is also a potent greenhouse gas.

Petroleum refining generates hazardous liquid and solid wastes, as well as air emissions. These facilities have pollution control requirements similar to many other large industrial and chemical plants, but leaks of toxic compounds occur nevertheless.

Hydroelectricity

The major environmental impacts of large hydropower production projects result from the initial construction of the hydropower facilities, filling the reservoirs, and changing river flows. This is in contrast with other energy sources, for which major impacts are spread over the entire fuel cycle.

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[91] U.S. Congress, Office of Technology Assessment, *The Direct Use of Coal*, OTA-E-86 (Springfield, VA: National Technical Information Service, April 1979), p. 186.

[92] Ibid.

[93] For a discussion of the technologies related to ocean spill cleanup, see U.S. Congress, Office of Technology Assessment, *Coping With An Oiled Sea: An Analysis of Oil Spill Response Technologies*, OTA-BP-O-63 (Washington, DC: U.S. Government Printing Office, March 1990).

[94] Ibid. Many of the large spills listed in the OTA background paper occurred in or near developing countries.

Large dam construction often requires the clearing of lands for access routes and sometimes for removal of construction material, with resulting soil degradation and erosion. Filling the reservoir can flood large tracts of land, uprooting people and leading to loss of forests, wildlife habitat, and species diversity. For example the Akosombo reservoir on the Volta in Ghana, with a land requirement of 8,730 km^2, approaches the size of such small countries as Lebanon or Cyprus.[95] Some currently proposed very large dam projects would inundate highly populated valleys and require large-scale resettlement of local residents.

The Three Gorges Dam project under consideration for the Yangtze river in China would be the world's largest hydroelectric project, generating the equivalent of approximately one-fifth the hydroelectricity currently produced in all of China each year, as well as providing flood control. Debate over this project has continued for six decades because it would entail the resettlement of approximately 1 million people; because it would deface one of China's most famous natural sites, and because critics believe that power could be provided more cheaply with smaller thermal and hydroelectric plants or through conservation.[96]

Dams disrupt the natural flow of rivers. Changed flows can erode riverbeds, alter flood patterns, harm aquatic ecosystems, and interrupt the spawning and migratory patterns of fish and other species. The introduction of a new lake can affect water tables and groundwater flows and interfere with the necessary flow of nutrients, and may induce microclimatic changes in humidity, cloud cover, and rainfall. In addition, if the vegetation is not cleared from the reservoir area before flooding, rotting organic matter releases significant amounts of CO_2 and methane, two potent greenhouse gases.

Hydropower facilities, in turn, are vulnerable to environmental degradation. Heavier than expected siltation of reservoirs from deforested and/or degraded lands upstream can reduce the lifespan of hydroelectric projects (see table 5-4).[97] The Hirakud reservoir in India, for example, was expected to be productive for about 110 years, but now has an estimated productive lifetime of 35 years.[98] In Costa Rica, excess sedimentation from soil eroded from steep slopes planted with coffee trees over the past 20 years has caused estimated losses of $133 million to $274 million at the Cachi hydroelectric station.[99]

Dams and the irrigation schemes dependent on these dams have also contributed to increased incidence of debilitating diseases, such as schistosomiasis.[100] Smaller hydroelectric systems and better management may minimize some of the above adverse consequences.

Biomass

Biomass fuels, which are critical to the rural and poor urban sectors of developing countries (chs. 2, 3, and 4), can have a variety of environmental impacts. These are discussed above and are closely intertwined with deforestation, desertification, and rural air quality. A later report from this study will examine the environmental effects of biomass use in detail, particularly in the context of producing clean biomass fuels (e.g., ethanol) and using them to fuel modern equipment.

Nuclear Energy

Nuclear energy currently makes little contribution to the overall energy requirements of developing countries. Seven developing countries produce uranium: South Africa, Niger, Gabon, India, Argentina, Brazil, and Pakistan.[101] Eight developing countries had operating commercial reactors as of late 1989 and several more had commercial reactors under construction (ch. 4). A total of 28 developing countries had research reactors as of late 1988.[102]

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[95] R.S. Panday (ed.), *Man-made Lakes and Human Health* (Paramaribo: University of Suriname, 1979).

[96] Robert Delfs, "Wealth and Woe: The Long Struggle to Harness the Waters," *Far Eastern Economic Review*, vol. 147, Mar. 15, 1990, pp. 22-23; Sheryl WuDunn, "In China, Dam's Delay Spares a Valley for Now," *New York Times*, Apr. 18, 1989, p. C1.

[97] U.S. Congress, Office of Technology Assessment, op. cit., footnote 41, p. 43.

[98] Ibid., p. 43.

[99] David Dudenhoefer, "Forest Crisis Nears," *The Tico Times*, vol. 34, Feb. 16, 1990.

[100] United Nations Food and Agricultural Organization, op. cit., footnote 7, p. 69.

[101] United Nations, *Energy Statistics Yearbook, 1986* (New York, NY: 1988).

The conventional nuclear fuel cycle includes uranium mining and processing, fuel fabrication, electricity generation, and radioactive waste disposal. Each of these steps has the potential to release varying amounts of toxic and/or radioactive materials to the environment. Releases usually take the form of small leakages but have, on rare occasion, also resulted in catastrophes such as Chernobyl. On the other hand, the nuclear power option releases little carbon dioxide or other greenhouse gases to the atmosphere, nor does it emit much sulfur dioxide, nitrogen oxides, or other air pollutants.[103] These tradeoffs pose difficult environmental choices.

Solar, Wind, and Other Renewable Energy

Solar energy can be used to heat water or dry crops, or can be turned directly into electricity by photovoltaic cells. Winds can be harnessed for pumping water or generating electricity. Though holding great promise for the provision of decentralized forms of energy for remote areas, as yet these sources provide only small amounts of energy for developing countries.

Geothermal energy, though still a very small part of total energy supply in developing countries, is being used in several Latin American and Asian developing countries and in Kenya. The environmental problems associated with geothermal energy production are highly dependent on the geochemical characteristics of each specific site and the extent to which good environmental practice is followed. Potential adverse environmental impacts include the release of gases (particularly CO_2), contamination of local aquifers by saline (and sometimes toxic) geothermal fluids into groundwater, subsidence of land overlying wells from which geothermal fluids have been extracted, and the generation of high-temperature liquid effluents containing metals and dissolved solids. With existing economically proven technologies and good management, however, these potentially adverse impacts can be kept under control.

Greenhouse Gases and Global Climate Change

The environmental impacts described above are largely limited to the individual countries concerned. Some activities—notably, the combustion of fossil fuels and deforestation—can have a wider impact, including impacts on the global climate. An international panel of scientific experts of the Intergovernmental Panel on Climate Change (IPCC)[104] recently concluded that: "emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the natural greenhouse effect, resulting, on average, in an additional warming of the Earth's surface."[105] Under the IPCC "Business as Usual" scenario, emissions of carbon dioxide are projected to grow from approximately 7 billion metric tonnes of carbon in 1985 to 11-15 billion metric tonnes in 2025.[106] Methane emissions are projected to increase from 300 million metric tonnes in 1985 to 500 million metric tonnes by 2025. Based on current models and with these trends in greenhouse gas emissions continuing, scientists predict that global mean temperature will increase at a rate of about 0.3 °C per decade during the next century, a rate higher than that seen over the past 10,000 years.[107]

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[102] World Resources Institute, *World Resources 1990-1991* (New York, NY: Oxford University Press, 1990). Installed capacities are inadequate indicators by themselves, as capacity factors for nuclear, thermal, and hydroelectric plants vary considerably. Installed capacities and capacity factors can be found in World Bank, "Summary Data Sheets of 1987 Power and Commercial Energy Statistics for 100 Developing Countries," Industry and Energy Department Working Paper Energy Series No. 23, March 1990.

[103] Some carbon dioxide may be released during mining, transport, or other operations by fossil-fueled equipment, and some may be released in fabricating the construction materials—particularly cement.

[104] The Intergovernmental Panel on Climate Change (IPCC) is an international task force created by the World Meteorological Organization and the United Nations Environment Program. Initiated in 1987, this body focuses on analyzing current information available on climate change issues and devising strategies to address climate change.

[105] Intergovernmental Panel on Climate Change, "Policymakers' Summary of the Scientific Assessment of Climate Change: Report to IPCC From Working Group I," June 1990, p. i.

[106] Intergovernmental Panel on Climate Change, Working Group III (Response Strategies Working Group), "Policymakers' Summary of the Formulation of Response Strategies: Report Prepared for IPCC," June 1990, p. iii.

[107] IPCC Working Group I, op. cit., footnote 105, p. ii.

More than half of the warming has been attributed to carbon dioxide. Atmospheric concentrations of carbon dioxide have increased by about 25 percent since preindustrial times. This rise is largely due to carbon dioxide emissions from the burning of fossil fuels and from deforestation.

In 1985, according to estimates for the IPCC Working Group III, developing countries contributed about one-quarter (26 percent) of annual global energy sector CO_2 emissions;[108] three-fourths came from the industrialized market countries and the centrally planned European countries (including the U.S.S.R.). By 2025, with expanding populations and rapidly increasing energy use, developing countries are projected to produce roughly 44 percent of global energy sector CO_2 emissions.

While the CO_2 emissions from the energy sector are fairly well known, there are large uncertainties about the contribution of emissions from deforestation and other land use changes. This makes it difficult to calculate with confidence the developing country share of both total annual and cumulative emissions for CO_2 and other gases. Estimates of the CO_2 emissions from tropical deforestation differ by a factor of four.[109] By various estimates, deforestation could be the source of between roughly 7 to 35 percent of total annual CO_2 emissions. Developing countries are also responsible for at least half of the global anthropogenic generation of two other important greenhouse gases, methane and nitrogen oxides.

In addition to increases in mean global temperature, other effects expected to occur with global warming would include increases in sea level[110] and shifts in regional temperature, wind, rainfall, and storm patterns. These, in turn, would submerge some low-lying coastal areas and wetlands, threaten buildings and other structures in these areas, and increase the salinity of coastal aquifers and estuaries. Such changes could disrupt human communities and aquatic and terrestrial ecosystems and affect food production and water availability.[111] A number of developing countries may be especially vulnerable to these effects.[112] No one, however, can yet predict the timing, severity, or extent of the potential impacts with certainty.

The IPCC scientists also noted that climate models suggest that controlling emissions can slow global warming, perhaps from 0.3 to 0.1 °C per decade. Emission control strategies that countries could consider today include improved energy efficiency and cleaner energy sources—strategies that may also have economic benefits. The expansion of forested areas, improved livestock waste management, altered use and formulation of fertilizers, and improved management of landfills and wastewater treatment might also reduce or offset emissions.

Achieving meaningful reductions in emissions will require unprecedented levels of international cooperation and must include developing countries. In addition to the technological challenges for the energy, agriculture, and industrial sectors, governments of the industrial and developing countries face challenges in improving and expanding institutional mechanisms for technology transfer to developing countries for providing vital energy services while limiting emissions. These issues are discussed in the forthcoming OTA report *Changing By Degrees: Steps To Reduce Greenhouse Gases*.

Government Policies

Responses to the deteriorating quality of the environment in developing countries show a mixed picture. On the one hand, progress is being made in setting up the government apparatus of environmental control, and concern and activity at the grassroots level is rising rapidly. On the other hand, implementation of environmental policies is frequently difficult to achieve, and progress is sometimes impeded by unintended environmental impacts of other policies.

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[108] IPCC Working Group III, op. cit., footnote 106, p. 10, table 2.

[109] IPCC, "Policymaker's Summary of the Formulation of Response Strategies: Report Prepared for IPCC by Working Group III," June 1990, p. 5. Estimates of CO_2 emissions from deforestation and land use changes (including wood fuel) were 0.6 to 2.5 PtC in 1980 according to a report prepared for the IPCC Working Group 1. "Scientific Assessment of Climate Change: Peer Reviewed Assessment for WG1 Plenary Meeting, May 1990," Apr. 30, 1990, p. 1-9. More recent evidence from selected countries would indicate deforestation rates now are higher than they were in 1980. Estimates of CO_2 emissions in 1987 were 5.7 +0.5 PtC from fossil fuel burning and total emissions were of 7 +1.1 PtC.

[110] The IPCC working group predicted an average rate of global mean sea level rise of about 6 cm per decade over the next century, 20 cm by 2030, and 65 cm by the end of the century with significant regional variations. This increase is primarily due to thermal expansion of the oceans and melting of some land ice.

[111] Intergovernmental Panel on Climate Change, "Policymakers' Summary of the Potential Impacts of Climate Change: Report from Working Group II to the IPCC," May 1990, p. 8.

[112] J.D. Milliman et al., "Environmental and Economic Implications of Rising Sea Level and Subsiding Deltas: The Nile and Bengal Examples," *AMBIO*, vol. 18, 1989, pp. 340-345.

The past two decades have seen considerable environmental policymaking activity in the developing world, including the establishment of national environmental agencies and organizations[113] and the adoption of laws and practices designed to prevent environmental pollution and degradation or to protect unique natural environments and wildlife. All in all, more than 100 developing countries now have governmental bodies whose responsibilities include environmental protection.[114] However, only a limited number of countries[115] have established independent environmental agencies in their central governments. Most have increased their environmental oversight capabilities by creating or expanding sections or offices within environment-related government departments such as agriculture, energy, fisheries, forestry, irrigation, natural resources, or tourism.

The larger developing nations with traditions of extensive government policymaking and implementation and a relatively advanced domestic research base have formulated and adopted a variety of environmental protection laws and standards, including the requirement of environmental impact statements for large projects. Developing countries with detailed nationwide air and water quality standards or with regulations specifying the levels of permissible pesticide residues in food are still, however, in the minority. Those that do have such regulations have usually based their legislation on the standards in force in the industrialized nations; consequently, their specifications—at least on paper—are usually as strict as and sometimes even stricter than, those of the industrial countries, although implementation may lag.[116]

Some developing countries have shown a significant commitment to protecting the environment. China's most polluted coal-burning cities have mean sulfur dioxide levels between 100 and 300 ug/m^3, about the same as in British cities prior to the introduction of Britain's Clean Air Act in the early 1950's. China, with levels of income much lower than the United Kingdom in the early 1950's, has already begun to respond to the problem by introducing cleaner urban fuels and outfitting coal-fired plants with effective particulate controls[117].

Environmental concerns in developing countries have not been limited to domestic issues. Developing countries have also participated in international environmental protection treaties. Most of the developing countries belong to the World Heritage, Endangered Species, and Law of the Sea conventions. Nine developing countries, including Mexico, Egypt, Morocco, and Venezuela, have already signed the Montreal protocol for protection of the ozone layer.

Many developing countries have also experienced an increase in grassroots environmentalism in addition to this official activity. In Ecuador, Colombia, Guatemala, and Brazil movements organized by citizen groups have led to the banning of toxic pesticides and the initiation of major urban cleanups.[118] Indigenous nongovernmental organizations (NGOs) have increasingly involved themselves in environmentally oriented efforts. More than 600 Brazilian and Indonesian NGOs currently are working on environmental issues, as are several thousand groups in India.[119]

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[113] Jeffrey H. Leonard and David Morell, "Emergence of Environmental Concern in Developing Countries: A Political Perspective," *Stanford Journal of International Law*, Issue 2, Summer 1981.

[114] Barbara J. Lausche, World Bank, "Environment and Natural Resources Management Institutions in Developing Countries," background paper, draft, Oct. 10, 1989.

[115] Bermuda, Burkina Faso, Gabon, India, Kenya, Oman, Papua New Guinea, Senegal, Singapore, Trinidad and Tobago, Venezuela, and Zaire.

[116] The Chinese daily average standard for ambient sulfur dioxide is stricter in each of the three classes (natural unpolluted areas, urban residential locations, and industrial districts) than the U.S. values; maximum nitrogen oxide levels permissible in residential areas are equivalent to the Japanese standard; and the maximum carbon monoxide levels allowed at any time are much lower than the 1-hour averages in West Germany or the United States. T.A. Siddiqi and C.X. Zhang, "Ambient Air Quality Standard in China," *Environmental Management*, vol. 8, 1984, pp. 473-479.

[117] Vaclav Smil, "Environment in Developing Countries," contractor report prepared for the Office of Technology Assessment, June 1990.

[118] World Resources Institute, "Development and Pollution in the Third World," paper prepared for the Tokyo Conference on the Global Environment and Human Response, Sept. 11-14, 1989, July 1989, p. 33.

[119] Ibid.

Despite these achievements, major problems remain. A fundamental constraint on environmental policymaking in all but a handful of developing countries is the absence of systematic, integrated data on the current state of environmental pollution and degradation. While there is sometimes a great deal of site-specific information connected with particular projects, virtually all the developing countries lack spatially representative networks for monitoring land, water, and air quality or accurately measuring the rates of deforestation or changes in agricultural land and soil quality. China and India, however, have accumulated a fairly extensive information base through the combined activities of various government departments and university-based researchers.

The implementation and monitoring of environmental policies and standards are also difficult. In most countries, the budgets of the environmental agencies are a small fraction of their minimum needs, and staffing is inadequate. Enforcement is often lax; prosecutions are often costly, uncertain, and slow; and the punishments actually meted out may be inadequate deterrents.[120]

Environmental protection is also sometimes impeded—in both developing and industrialized countries—by government policies intended to promote economic growth, generate employment, service foreign debts, or meet other important national needs. In Brazil, for example, a variety of government policies have encouraged rapid development—and thus rapid deforestation—of the Amazon. These include tax exemptions, tax credits, subsidies of rural credit, and land acquisition laws (squatter rights).[121] These inducements have inadvertently encouraged a number of activities that would not be economical in the absence of direct or indirect government supports. For example, the implicit government subsidy for ranching alone during the period 1975 to 1986 has been estimated by the World Bank at more than $1 billion.[122] The Brazilian government has recently begun to reverse many of these policies as awareness of their costs and environmental impacts has grown.

Similarly, commercial logging has also been encouraged by many governments through low royalties and fees, reduced export taxes, and other tax breaks for timber companies and other domestic wood products industries.[123]

Tax credits, investment subsidies, and other fiscal supports may be necessary and justified to encourage needed development, and such policies are widely used in developing and industrialized countries. The value of depletable natural resources and the costs of environmental degradation, however, are often not properly accounted for by these financial instruments. For this reason, many economists advocate policies that more accurately include these costs than has sometimes been done in the past. With proper valuation of the natural resources, environmental impacts, and other costs and benefits, such investments might be made more wisely.[124]

Government policies in some industrialized nations may also inadvertently affect the environment in developing countries. In 1988, the European Community, the United States, and Japan provided subsidies to their agricultural sectors totaling $97.5 billion, $67.2 billion, and $57.8 billion respectively—a total of $222.5 billion.[125] This is nearly one-third of the GDP of the 2.8 billion people who live in low-income developing countries, and it is comparable to the GDP of their entire agricultural sector.[126] Some of these subsidies may tend to hold agricultural prices down in developing countries as well as limiting their export opportunities.[127] If this occurs and reduces developing countries' earnings for their agricultural output, they may have less incentive and ability to invest in agricultural research and development or infrastructure to achieve higher yields and quality. As noted above, low agricultural productivities (together with inequitable land tenure, etc.) contribute to the expansion of croplands into ecologically fragile areas. Similarly, import tariffs to protect domestic timber industries in industrial countries may encourage inefficient harvesting in tropical forests because the full market value of the resources cannot be obtained.[128]

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[120] Critiques of government enforcement of environmental laws in developing countries can be found in: R. Abracosa, and L. Ortolano, 1987, Environmental impact assessment in the Philippines: 1977-1985. *Environmental Impact Assessment Review*, vol. 7, pp. 293-310. C.M. Abraham and A. Rosencranz, 1986, "An Evaluation of Pollution Control Legislation in India," *Columbia Journal of Environmental Law*, vol. 11, 1986, pp. 101-118; H. Haeruman, "Conservation in Indonesia," *AMBIO*, vol. 17, 1988, pp. 218-222; A.D. Johns, Economic Development and Wildlife Conservation in Brazilian Amazonia," *AMBIO*, vol. 17, 1988, pp. 302-306; J. Mayda, "Environmental Legislation in Developing Countries: Some Parameters and Constraints," *Ecology Law Quarterly*, vol. 12, 1985, pp. 997-1024; K. Ramakrishna, "The Emergence of Environmental Law in the Developing Countries, a Case Study of India," *Ecology Law Quarterly*, vol. 12, 1985, pp. 907-935; A.S. Tolentino, "Legislative Response to Marine Threats in the ASEAN Subregion," *AMBIO*, vol. 17, 1988, pp. 238-242.

[121] The government suspended provisions that made clearing for ranches profitable and penalized owners of unimproved lands, but ranches are still attractive as a speculative hedge against inflation. See U.S. Congress, Office of Technology Assessment, op. cit., footnote 14; Climate Institute, "Climate News Around the Globe," *Climate Alert*, vol. 2, No. 3, Fall 1989, p. 8; S.B. Hecht, "The Sacred Cow in the Green Hell: Livestock and Forest Conversion in the Brazilian Amazon," *The Ecologist*, vol. 19, No. 6, November/December 1989, pp. 229-234.

[122] Hans P. Binswanger, World Bank, "Fiscal and Legal Incentives With Environmental Effects on the Brazilian Amazon," Agricultural and Rural Development Department, Operational Policy Staff, May 1987; N. Myers, *Deforestation Rates in Tropical Forests and Their Climatic Implications* (London: Friends of the Earth Limited, 1989).

[123] Robert Repetto, "Deforestation in the Tropics," *Scientific American*, vol. 262, No. 4, April 1990, pp. 36-42.

[124] Robert Repetto et al., *Wasting Assets: Natural Resources in the National Income Accounts* (Washington, DC: World Resources Institute, June 1989).

[125] Stuart Auerbach, "Statement Aimed at Farm Subsidies Impasse," *Washington Post*, July 12, 1990, p. A9.

However well-intentioned, the development policies of bilateral development agencies and multilateral development banks have also sometimes directly contributed to environmental degradation due to their emphasis on large projects—transportation infrastructures, hydroelectric facilities, and industrial complexes.[129] Development agencies are, however, becoming more sensitive to these environmental concerns.[130] The role of development agencies in promoting the adoption of more environmentally sound energy technologies will be examined in a later report of this OTA study.

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[126] World Bank, *World Development Report 1989* (Washington, DC: 1989), indicator tables 1 and 3. Note that this does not include the 1 billion people in middle-income developing countries who had a 1987 GDP of nearly $2 trillion.

[127] Vernon O. Roningen and Praveen M. Dixit, *Economic Implications of Agricultural Policy Reforms in Industrial Market Economies* (Washington, DC: U.S. Department of Agriculture, Economic Research Service, 1989).

[128] U.S. Congress, Office of Technology Assessment, op. cit., footnote 14.

[129] U.S. Congress, Office of Technology Assessment, op. cit., footnote 14; Bruce M. Rich, "The Multilateral Development Banks, Environmental Policy, and the United States," *Ecology Law Quarterly*, vol. 12, No. 4, 1985; P. Aufderheide and B. Rich, "Environmental Reform and the Multinational Banks," *World Policy Journal*, Spring 1988, pp. 301-321; W. Reid, "Sustainable Development: Lessons From Success," *Environment*, vol. 31, No. 4, May 1989, pp. 7-35.

[130] See, for example, World Bank, "A Review of the Treatment of Environmental Aspects of Bank Energy Projects," Industry and Energy Department Working Paper, Energy Series Paper No. 24, March 1990.

Appendix A

Glossary of Energy Units

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Glossary of Energy Units

British thermal unit (Btu)—The basic unit of energy in the English system of units. The energy required to heat 1 pound of water 1 °F. One Btu is about the energy given off by burning a single match tip.

Hectare (ha)—An area of land measuring 10,000 square meters or equivalently 100 meters by 100 meters. One hectare is equal to about 2.5 acres.

Joule (J)—A basic unit of energy in the metric system. A joule of energy is very small (a single match tip gives off about 1,000 joules), so joules are often multiplied by orders of ten (10, 100, 1,000, etc.) to yield useful units:

Name	*Value*	*Abbreviation*	*Equivalent*
kilojoule	thousand (10^3) joules	kJ	0.95 Btu
megajoule	million (10^6) joules	MJ	
gigajoule	billion (10^9) joules	GJ	
terajoule	10^{12} joules	TJ	
petajoule	10^{15} joules	PJ	
exajoule	10^{18} joules	EJ	0.95 quads

Total energy production and consumption for a country is typically given in exajoules; per capita energy consumption is typically given in gigajoules (1 GJ is equivalent to the energy in about 7.5 gallons of gasoline).

Kilogram (kg)—The basic unit of weight in the metric system, equal to 2.2 pounds.

Kilowatt (kW)—The *power* (energy per unit time) unit in which electricity is measured.

Kilowatthour (kWh)—The energy unit in which electricity is measured. A 100-watt light bulb burning for 10 hours consumes 100 W × 10 hours = 1,000 Wh = 1 kWh of energy.

Meter (m)—The basic unit of length in the metric system, equal to 39.4 inches.

Quad—10^{15} Btus. The United States currently consumes about 80 quads (80×10^{15} Btus) of energy per year. 1 Quad is equal to about 1.05 exajoules (EJ).

Tonne (t)—Short for metric tonne, equal to 1,000 kilograms or about 2,200 pounds.

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